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THE MOTIVATIONAL ASPECT OF AN IRRELEVANT DRIVE IN THE BEHAVIOR OF THE WHITE RAT [1]

BY WILSE B. WEBB [2]

From The Psychological Laboratory, State University of Iowa

THEORETICAL BACKGROUND OF THE PROBLEM

Among the problems of psychological theory that have been receiving considerable attention recently are those connected with the manner in which motivational and learning variables combine to determine behavior. So far as the general formulation of the problem is concerned there appears to have been a considerable amount of agreement among the different psychological theorists. Thus, such supposedly divergent positions as those represented by Hull (9), Lewin (14), and Tolman (22) offer very similar formulations.

These theorists, in general, agree that the behavior of an organism in a particular situation depends upon two main sets of factors, (1) the factor of habit, cognition, or learning as dependent upon past experience, and (2) the factor of present motivation. In each of these systems, neither one of these two sets of variables is deemed sufficient to account for behavior. Furthermore, all three theories seem to favor a multiplicative relation between the habit and motivational variables, such that a zero value of either of them implies a zero response tendency.

In his recent book, *Principles of behavior* (9), Hull has attempted to formulate in somewhat greater detail and specificity than Tolman and Lewin the basic laws governing the roles of habit (learning) and motivational conditions in the determination of behavior. His hypotheses are based primarily on studies of Perin (16) and Williams (23) carried out in the Yale laboratory. These investigations provided empirical data indicating that the strength of a simple instrumental response depended jointly upon the number of previous reinforced occurrences (learning) and the number of hours of food deprivation (drive). Making use of a series of hypothetical concepts in the form of intervening vari-

[1] This paper constitutes a portion of a dissertation submitted in partial fulfillment of the requirements of the degree of Doctor of Philosophy, in the Department of Psychology in the Graduate College of the State University of Iowa. The writer wishes to express his sincere appreciation to Professor Kenneth W. Spence for his many helpful suggestions and stimulating criticisms offered throughout the course of the experimental investigation. Portions of this paper were presented at the American Psychological Association Meetings of 1947.

[2] Now at the Washington University.

ables[3] Hull has proposed the following set of basic postulates to account for such behavior:

$$R = f(sE_R), \quad (1)$$

$$sE_R = f(sH_R \times D), \quad (2)$$

where: sH_R = habit structure, a hypothetical construct, which is some function of such variables as the number reinforced trials, delay in reward, etc.

D = drive strength, a hypothetical construct which is some function of the time of deprivation of a needed goal object (food, water, etc.) or the magnitude of some noxious stimulus or both.

sE_R = excitatory potential, a hypothetical construct.

R = response measure; i.e., number of trials for extinction, amplitude of response, etc.

The concept D in the formula (2) above is considered to be related not only to the dominant drive ($\bar{D}$) present in the organism but also to 'certain residual amounts of various other drives,' and these for convenience have been labelled $\dot{D}$. The alien or irrelevant drives active at the time "have the capacity to sensitize habits not set up in conjunction with them." Specifically D, representing the *effective drive state* actually operative in the organism, is formulated as follows:

$$D = \bar{D} + \dot{D}, \quad (3)$$

where: $\bar{D}$ = strength of relevant drive state, and $\dot{D}$ = strength of irrelevant drive states.[4]

[3] Bergmann and Spence (4), Spence (21), and Hull (10) should be consulted for a more amplified consideration of the conception and use of intervening variables. In general they may be considered as hypothetical constructs defined in terms of manipulable experimental variables which serve to ascertain the nature of the functional relationships (laws) holding between the dependent (R) variables and the independent, experimental (S) variables.

[4] Irrelevant drives are, for the purpose of this study, defined as those drives present in the organism which have not been rewarded in the learning situations. Relevant drives are those drives which have been reduced by this response, i.e., the original motivation under which the response is learned.

Thus, formula (2) may be written as follows:

$$sE_R = f[sH_R \times (\bar{D} + \dot{D})]. \quad (4)$$

It may be noted from the formulation above that D is considered as a generalized drive state to which all of the antecedent conditions resulting in specific drives contribute. The nature of the action of this 'generalized' drive state in Hull's system is described as follows. A habit structure (sH_R) is conceived of as being activated (the assumed relation is multiplicative) by D, no matter what the drive-producing condition may be. Thus, a habit that has been acquired under one dominant drive condition (e.g., hunger) will nevertheless be activated by D when this particular drive is no longer the dominant one. Thus, Hull (9, p. 252) writes concerning D:

> It "seems also to have a generalized but possibly weaker tendency to facilitate action of *all* effectors, giving rise to a degree of undifferentiated motivation analogous to the Freudian libido. . . . This, together with the assumption that one or more other motivations are active to some degree, explains the continued but limited amount of habitual action of organisms when the motivation on the basis of what the habit was originally set up has presumably become zero."

Of particular interest to the present paper are the behavioral consequences predicted by this system when the relevant drive has been satiated. It will be noted from formula (4) and the quotation cited above that Hull has hypothesized that even when the relevant drive has been satiated, response evocation should nevertheless continue as a function of the presence of irrelevant drives.

This theoretical influence of irrelevant drives when the animal is satiated for the relevant drive is formally stated in Corollaries VII, VIII and X in Chapter XIV of Hull's *Principles of behavior:*

> Corollary VII: Under the condition of the satiation of the dominant drive involved in the original habit-acquisition there are sufficient residuals of other drives which in the aggregate yield on the average an excitatory potential amounting to around 20% of that mobilized by a twenty-four hour hunger on a habit originally set up on the basis of this drive (9, p. 248).

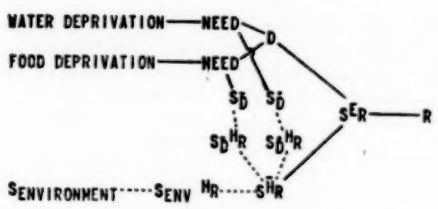

FIG. 1. Diagrammatic representation of the relationships hypothesized by Hull as existing between habit, drive, drive stimuli, and response when that response tendency has been developed under a relevant drive state of hunger and an irrelevant drive state of thirst. The symbols of this diagram have been previously identified.

Corollary VIII: In case an organism is presented with all the stimuli characteristic of a habit, if the original drive is replaced by a strong second drive whose S_D[5] activates no conflicting habit tendency, the reaction potential to the execution of the habitual act will be stronger than would be the case if the irrelevant second drive were not active (9, p. 248).

Corollary X: The number of reinforcements being constant, the stronger an allied but irrelevant drive active at the time of extinction, the greater will be the number of unreinforced evocations required to reduce the reaction potential to a given level, though this number will be materially less than would be required under the same intensity of the relevant drive (9, p. 249).

In the development of these corollaries a further notion concerning the role of drive in behavior theory is introduced. This notion concerns the role of the S_D as it enters the stimulus complex and its effect on the habit structure itself with the modification of this stimulus complex. Hull makes note of this effect in the following quotation:

> . . . When the hitherto dominant drive ceases to be active, not only is there lost the . . . drive strength previously contributed by this need, but there is also lost to the conditioned stimulus compound the sizable component made up by S_D, the withdrawal of which materially reduces the available habit strength associated with the situation in question, and so reduces the resulting reaction potential (9, p. 248).

[5] S_D here, and throughout this paper, is to be taken as the symbolic representation of 'drive stimulus.' These 'drive stimuli' are thought of as localized stimuli arising from and associated with particular conditions of need, e.g., stomach contractions are the S_D usually thought to be associated with hunger.

A more complete formulation of Hull's theory is schematically diagrammed in Fig. 1.

We note from this diagram that, subsequent to certain antecedent conditions (deprivation of some goal object or the presence of some noxious stimulus), a condition of need or needs will occur. From a condition of need, a stimulus drive condition (S_D) and a drive condition (D) arise. When this S_D condition occurs in conjunction with some environmental stimulus-response sequence which is followed by a reinforcing state of affairs, a resultant ${}_{S_D}H_R$ increment is acquired. This ${}_{S_D}H_R$ and the S(environment)H_R together constitute the effective habit structure, ${}_S\bar{H}_R$, for the particular S–R sequence. The habit structure acts in a multiplicative fashion with the D to result in the reaction potential of the organism at a particular moment (${}_SE_R$). ${}_SE_R$ results in, and is measured by, some response on the part of the organism.

An examination of these concepts indicates that the problem of the role of the irrelevant drive in Hull's theorizing may be bifurcated into two parts:

1. The effect of an irrelevant drive on response evocation by its contribution to the general drive condition (D).

2. The effect of an irrelevant drive on response evocation through the action of specific drive stimulus (S_D) and its habit tendency.

As one type of experimental evidence bearing on the role of irrelevant drives in response evocation, Hull cites certain results of studies by Zener and MacCurdy (25), Finch (7), and Skinner (19).

These experimenters have shown that the strength of response did not become zero when the relevant drive was satiated but varied between 17 and 24 percent of the response measure obtained when the relevant drive was based upon 24 hours deprivation of the goal object. The fact that curves fitted on the basis of his theory to Perin's experimental data gave by extrapolation response values for the zero relevant drive condition of approximately 28 percent of the response strength at 22 hours drive ($\bar{D}$), was accepted by Hull as further evidence of the same type. He interpreted these data as evidence for the presence of irrelevant drives ($\dot{D}$) which he conceived as activating the habit structures of the stimulus situation to produce a super-threshold amount of reaction potential ($_{S}E_{R}$) and hence response.

Other, more recent, studies which might be cited in this same connection have been interpreted somewhat differently by their authors as evidence for the operation of secondary drives rather than irrelevant primary drives.[6] Anderson (2, 3) for example, in a study in which he used a 14-unit T maze, found that satiated animals not only ran the maze but made a considerably below-chance number of errors. Furthermore he found that as the training increased, satiation of the relevant drive had less and less of a deleterious effect on the accuracy of performance in the maze. Brogden (5) has reported similar evidence in a conditioning experiment with dogs and he interprets his data as supporting Anderson's theory of the 'externalization of the drive.'

[6] Unfortunately, Hull has not as yet dealt with secondary drives, but it is entirely possible that when he does he will conceive of these secondary drives as also contributing to the general drive state, *D*. It would hardly seem proper, however, to refer to these secondary drives as irrelevant as they are derived in some manner from the relevant drive. In the event secondary motivation becomes a well established phenomenon, studies involving *only* satiation of the relevant primary drive cannot be expected to throw much light on the role of irrelevant drives.

In addition to this secondary motivation interpretation, there are certain other theoretical positions which would not invoke the presence of an irrelevant drive to account for the continuance of a response in a situation under satiation of the relevant drive. Allport's (1) concept of 'functional autonomy' and Woodworth's (24) notion that 'any mechanism might be a drive' are cases in point. Both of these conceptions are somewhat vague, however, and do not seem to go much beyond the assertion that strong habits appear to possess intrinsic motivational properties.

Not all of the experimental evidence, however, has shown that a learned response will continue to be made when the relevant drive is satiated. Siegel (18), in a study which was designed to test Anderson's findings and theoretical interpretations, presents conflicting evidence. Satiated animals continued to run with no appreciable error on a previously learned elevated 10-unit T maze. However, it was found that when a four-unit linear maze had been learned and the animals were satiated, chance scores were obtained regardless of the level of training. Both Anderson and Siegel found a marked increase in latency times for the satiated animals.

Using the same type of Skinner box employed by Perin and Williams in their studies, Koch and Daniels (13) failed to confirm the extrapolated response values at zero value of the original learning motivation as calculated by Perin and Hull. After establishing a strong bar depression habit (70 reinforcements) Koch and Daniels reported that they found the strength of response 'strikingly close to zero' when the animals were satiated Furthermore, they offer criticisms of the studies (7, 19, 25), cited by Hull to the effect that none of these investigators obtained complete satiation of the relevant drive during their experimental tests. They consider their own finding to have resulted largely from the fact that their method produced more or less complete satiation. Their technique incidentally was identical with that employed by Perin. It is interesting to

note that these investigators conclude that their findings support Lewin's position that strong habits do not acquire intrinsic motivational properties and that "no matter how strongly learned a behavior tendency may be, the behavior tendency will not be manifest during the absence of relevant motivation (need, tension)" (13, p. 180).

When we turn to experiments in which a deliberate attempt has been made to vary the irrelevant drive and notice its effect on response strength we find only a few studies. Kendler (10, 11) has reported a study in which an irrelevant drive (thirst) was systematically varied in conjunction with the drive condition (hunger) which was rewarded during learning. Using a Skinner box, Kendler was able to demonstrate that response evocation was significantly affected by the presence of an irrelevant drive when operating in conjunction with the relevant drive. It was indicated in this study that the irrelevant drive had the effect of increasing response tendency up to a certain value of the irrelevant drive and thereafter, with further increase in the level of the irrelevant drive, a decreasing response tendency was obtained. These results are in contrast to Hull's hypothesis of an additive effect of the irrelevant drive which was indicated in formula (5).

In a later study, Siegel (17) obtained results which he interpreted as failing to support the conclusions of Kendler concerning the contribution of an alien drive to the general motivational level of the organism. It should be noted, however, that his study made use of the irrelevant drive conditions which already had been shown by Kendler to be least contributive to response evocation. Further work by Kendler (12) has been concerned with the conditioned role of this irrelevant drive but is not considered here as part of the present problem.

Statement of the Problem

It may be noted that in attempting to answer the question—how will an organism respond, given a maximally strong habit structure, when the drive state under which this habit structure was formed is satiated?—the systematic treatment of Hull finds the role of the irrelevant drives critical. Specifically, Hull makes his predictions concerning behavior under such circumstances on the basis of the presence and degree of the existing irrelevant drives in the organism. The role of the irrelevant drive under these circumstances, it has been suggested, is twofold: (1) acting as a contributor to a 'generalized drive' state, D, which in conjunction with the habit structure, functions as a determiner of response strength, and (2) acting as a contributor to the habit structure *per se*, through the conditioning of the irrelevant drive stimuli to the response tendency.

This study was designed to test the role of an irrelevant drive (thirst) in activating a habit structure under conditions of satiation of the drive under which the habit structure was originally developed (hunger). In this experiment the irrelevant drive was not present during training and hence could act presumably only in the first of the two roles, i.e., as a contributor to the generalized drive strength, D. Reaction potential and hence response strength, which is postulated as being some monotonic function of reaction potential, should increase with increase in the intensity of the thirst drive. Our primary interest is whether the posited increase in response measures occurs as a function of increasing strengths of the irrelevant drive and, if it does, what is the form of the function relating this measure to the period of deprivation of water.[7]

[7] A second study dealing with the conditioned role of the irrelevant drive was performed as part of the present experiment. These data are being analyzed and will be prepared for publication at a later time.

Experimental Procedure

Subjects.—The subjects of this experiment were 50 male white rats and 38 female white rats. Of these, 64 were from the colony maintained by the Psychology Department of the State University of Iowa; the remaining animals (12 males and 12 females) were obtained from the colonies of the Physiology and Biochemistry Departments of the University. With the exception of 18 animals, the male subjects were randomized between the five conditions of this experiment. Eighteen animals were randomized among three conditions (Conditions I, IV, and V, cited below). It is felt that no bias resulted from this failure of complete randomization. This assumption was partially tested by grouping these 18 animals and comparing their results with the remaining 22 animals of these three groups. By use of the *t* test the null hypothesis could be rejected at only the 40 percent level of confidence.

The females were randomized among seven conditions (the five conditions of this experiment and two conditions of Experiment II).

Apparatus.—The apparatus (Fig. 2) consisted of a stimulus box, the dimensions of which were 16 × 16 × 18 in. The sides of the box were painted a flat white. The top was open and the floor consisted of a brown masonite material. In one wall of the box a square hole, 1.75 × 2.25 in. was cut midway between the two adjacent walls and three inches above the floor. Behind this opening was a hinged door which opened back and upward. The door, painted a medium gray,

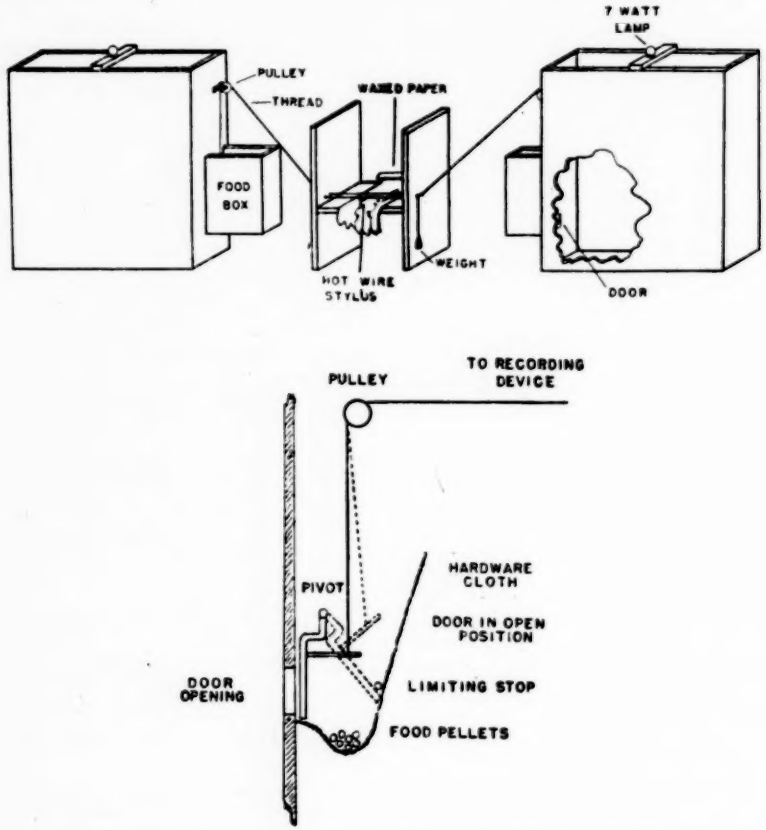

Fig. 2. Scaled diagram showing the test apparatus, the recording device, and a view of the food box and door (lower figure)

was counterbalanced so that it opened with a very light pressure. An overhead lamp of low intensity illuminated the interior of the box.

Opening the door gave access to a food tray which was one and one-half inches below the level of the door opening. The recess in which the food pellets rested was two inches back from the door opening. The maximum degree to which the door opened (measured from the bottom of the entrance hole) was two and three-quarters inches.

The task of the subject was to open this door and obtain a pellet of food. It was found that no food release mechanism was required since the animals would, upon training, open the door and obtain only one pellet of food each time.[8]

A recording system was devised which would yield a permanent record of the time the door was held open during each response, the number of responses made, and the total time required for extinction. As indicated in Fig. 2, a thread (radio dial cable) was attached to a bar projecting from the door (see inset portion of diagram). This thread was run over a pulley directly above the door and through two glass beads. The thread was weighted at its terminal point. In the area between the glass beads, a constant speed waxed paper polygraph was installed at right angles to the thread. A stylus, whose recording tip was heated by passing a current through a high resistance wire, was attached to the thread and touched the polygraph paper. When the door was closed a 'base line' was drawn by this stylus as the paper was moved by the polygraph. As the door opened, the thread, kept taut by the attached weight, would move in direct relation to the opening of the door.

Since the polygraph moved at a constant speed, measurement along the base line yielded measures of time. By noting the time of the beginning of a measurement period and measuring the distance between this point and the cessation of the last response of the animal, the total time during extinction could be obtained. Measurement of the time during which the stylus had departed from the base line yielded the amount of time the door was open during a response. Finally, a count of the number of times that the marker departed from the base line yielded the number of responses made by an animal. An arbitrary time of 2.4 sec. (.1 cm.) was used as a required time interval for the door to be closed for responses to be recorded as discrete reactions.

In order to expedite experimentation, two experimental boxes, made as identical as possible were employed. To test the possibility of a box difference (a difference attributable to inherent differences in the boxes), the results from the two boxes were compared. Since the animals run under each condition were split equally between the boxes, the total for the 40 animals run in Box 1 were compared with the 40 animals run in Box 2. A critical ratio was obtained for the two groups on the number of responses during extinction and the time the door was open during extinction. These critical ratios, .03 and .45, respectively, indicate that the difference between the boxes were not significant. In the light of these results, the measures obtained from the two boxes have been considered identical and throughout the paper have been treated without regard to the box from which the measure was obtained.

Training procedure.—All animals were placed on a 23-hour feeding schedule at least seven days prior to the first day of training. During this period they were handled frequently so as to reduce their emotional responses to handling to a minimum. Two animals were rejected prior to training as too emotional.

The procedure for training is outlined below on a day-to-day basis. All animals were under a 22-hour hunger drive during training. The different conditions of motivation holding during extinction for the different groups are shown under the motivational section which follows.

Day 1: a. Each subject was first given five min. in the stimulus box with no reinforcement of the door-opening response. (A count of the number of random responses occurring during this period revealed that 76 percent of the animals gave less than two responses.)

b. Five pellets (approximately .15 gm. each) were placed in the food recess and the door held open. Three animals were eliminated at this point because they did not meet an arbitrary criterion of eating one pellet in 10 min.

c. The animals obtained 10 pellets of food by pushing the door open and taking the food. The animals were then removed and after approximately one-half hour were fed 7½ gm. of Purina Dog Chow.

Day 2: Thirty pellets were obtained by pushing the door open. These reinforcements were given in groups of 10 pellets. Between each group of 10 pellets the rat was removed to a cage containing a water supply.[9] The animals were

[8] In the training procedure, the food tray was filled with 10 pellets at the beginning of each unit of 10 trials. When all but two to three pellets had been consumed by the animals during 10 trials, the tray was refilled with 10 more pellets.

[9] At this point a critical possibility must be recognized. It has been noted that removal from the stimulus box after trials 10, 20, 30, 40, 50, 60, 70, 80, and 90 may have acted as a reinforcement of the door-opening response as a

reintroduced to the apparatus after approximately 20 min. In this way the thirst drive was held to a minimum. During training the latency of the first response of each of the series of 10 responses was measured by a stop watch. Approximately one-half hour after this training the animals were fed 4½ gm. of Purina Dog Chow and removed to their home cages.

Day 3: Same as Day 2.

Day 4: Same as Day 3.

Day 5: Extinction to a three-minute criterion of no response of opening the door. The particular drive conditions for this extinction are outlined below.

Motivational conditions.—As indicated above, the training drive was that of 22 hours of food deprivation. During the extinction period the following conditions were maintained for the five groups of this experiment:

Following the last trial of Day 4 the subjects were placed in a feeding cage and given four and one-half grams of Purina Dog Chow. Each subject was then treated according to the motivational condition to which it had been previously assigned.

Group I (H-0:T-0). This group was returned to a home cage and remained there until the following day. A water bottle was available at all times. Two hours prior to their regular running time they were placed in a feeding cage containing several Purina Dog Chow pellets and a water bottle. They were allowed to eat for 30 min. At the end of this period, a supply of Puppy Pellets (Purina) was introduced into the feeding cage. Fifteen min. later, wet mash (Purina Dog Chow and condensed milk) was introduced. When the animals appeared satiated (no eating for approximately five min.) they were fed by hand until food was refused. At this time they were placed in a 'test' cage containing all three types of food. If food was refused for five min. they were considered satiated and removed to the experimental apparatus.

Group II (H-0:T-3). This group was treated the same as Group I immediately following the last day of conditioning. In the home cage, however, no water supply was available. Three and one-half hours prior to the regular running time a water bottle was introduced into the home cage and left for one-half hour. One hour prior to their regular running time they were placed in a feeding cage containing no water supply but an ample supply of Purina Dog Chow pellets. At the end of 30 min. a supply of Puppy Pellets was introduced into the feeding cage. When the animals refused to eat for approximately five min. they were hand fed alternately with Purina Dog Chow pellets and Puppy Pellets until both were refused. When food was refused from hand feeding, they were placed in a 'test' cage containing the two types of food cited above but with no water supply. When food was refused for five min. they were considered satiated for food and placed in the experimental apparatus.

Group III (H-0:T-12). The treatment of these subjects was identical with that of Group II except that the water bottle was introduced 12½ hours prior to their running time and removed one-half hour later.

Group IV (H-0:T-22). The treatment of these subjects was identical with Groups II and III except that no water bottle was introduced into the home cage.

Group V (H-22:T-0). These animals were fed after their training on Day Four. They were then returned to their home cage with a water bottle available at all times. At their regular running time they were placed in the test apparatus.

Conditions of extinction.—On the fifth day of the experiment and following the above-outlined procedures, each animal was placed in the experimental box which was thoroughly cleaned prior to each extinction group. No food was placed in the food tray. The animal was allowed to respond until no door-opening responses occurred in a three-min. period. The animals were then removed from the apparatus.

Results and Discussion

Equivalence of original learning.—The interpretation of the results of this experiment is based on an exami-

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'thirst satisfying' response. In noting this criticism the following points seem pertinent:

1. The animals in the test situation were operating under a minimal thirst motivation.

2. In terms of actual behavior, data were kept on 25 animals of Groups I through V. It was noted that two, six, and eight animals actually drank in the retaining cage between trials 10, 20, and 30 respectively.

3. If reinforcement did occur, *differential* reinforcement of the door-food-water behavior was only possible in nine of 90 trials and this occurring after immediate food reinforcement, a delay of eating, handling and being placed in the retaining cage. The door-food response was *differentially* reinforced in all 90 trials.

4. Water was never obtained directly by a door-opening response and was always obtained by the distinct behavior requirement involved in drinking from a tube.

In the light of these points it seems reasonable to assume that reinforcement of the door-opening response was minimally related to the thirst drive.

TABLE I

VARIANCES, RATIOS, AND *F*'S OBTAINED FOR LATENCY MEASURES TRIALS 1 AND 20, DAY 3 (GROUPS I–IV)

Variance	Ratios			*F*		
	Trial 1	Trial 20	d.f.	Trial 1	Trial 20	*F* (5%)
Motivational condition / Within groups	119.44 / 128.93	40.79 / 19.55	3 / 64	0.93	2.08	2.75
Sex / Within groups	265.23 / 128.93	24.03 / 19.55	1 / 64	2.06	1.23	3.99
M × S / Within groups	95.76 / 128.93	11.01 / 19.55	3 / 64	0.74	0.56	2.75

nation of the responses made by the groups during extinction. In order that we may attribute any obtained differences in response between these groups to a difference in the motivational conditions during this period, it is essential that the amount of learning prior to extinction be equal for all groups. The necessity of such an equivalence from group to group follows from the assumption that response will be a jointly determined function of the habit strength resulting from past training and the drive strength present at the time of extinction.

In the original learning, every animal, under identical conditions of motivation (22 hours of hunger), received 100 reinforcement trials. Except for sampling variations, this procedure should have resulted in equal learning (habit strengths) among the groups. Experimental evidence which supports such an assumption may be found in an examination of the latency of the response of opening the door (measured from entrance into the box) during the last day of training. The latency of a response may be considered a measure of habit strength when the drive is held constant. Any difference in habit strength from group to group should then be reflected in differences in latency measures of the groups since motivation during training was equal in all the groups.

Analyses of variance of the latency measures of the 1st trial and the 20th trial of the last day of training were carried out. The results of these analyses are presented in Table I.

The failure to obtain a significant *F*-ratio for the variance between groups (conditions variance/within groups variance) indicates that we may not reject the null hypothesis concerning differences among the latencies (and hence the habit strengths) of the groups on the day prior to extinction.

Extinction data.—The results of the extinction period, in terms of the three response measures employed, are summarized in Table II.

An application of Bartlett's test for homogeneity (**20**, p. 250) of variance to these measures indicated that the null hypothesis with respect to differences between the variances of the groups could not be rejected.[10]

An analysis of variance into four components (Groups I, II, III, and IV) was then performed for the three extinction measures. An inspection

[10] The null hypothesis could only be rejected at approximately the 10 percent level of confidence in the three measures obtained.

TABLE II

MEANS AND SIGMAS, BY GROUPS AND SEX, OF THE THREE MEASURES OBTAINED DURING EXTINCTION I, EXPERIMENT I

Group	N	Motiv. Cond.		No. Resp. to Extinct.		Time Door Open (sec.)		Total Time to Extinct.	
		Hunger	Thirst	Mean	Sigma	Mean	Sigma	Mean	Sigma
All Subjects									
I	18	0	0	2.8	1.74	4.0	4.34	70.5	67.62
II	18	0	3	5.2	2.77	11.6	9.95	192.7	94.79
III	18	0	12	5.1	2.90	9.8	7.12	146.2	93.22
IV	18	0	22	7.2	3.94	13.5	8.86	236.9	118.51
V	16	22	0	14.2	7.14	32.3	18.43	384.9	199.6
Male Subjects									
I	10	0	0	3.2	1.53	3.9	2.57	82.4	73.8
II	10	0	3	5.3	2.83	12.7	12.46	194.5	112.1
III	10	0	12	4.9	2.51	9.2	3.93	136.1	87.4
IV	10	0	22	7.5	4.06	13.8	10.27	287.9	140.6
V	10	22	0	12.8	5.79	29.8	19.55	379.4	207.4
Female Subjects									
I	8	0	0	2.4	1.87	4.1	5.81	55.3	55.28
II	8	0	3	5.1	2.72	10.4	5.01	190.4	67.21
III	8	0	12	5.4	3.31	10.9	8.34	158.8	98.58
IV	8	0	22	6.9	3.75	13.1	6.69	173.3	68.06
V	6	22	0	16.5	5.79	36.8	15.52	394.0	181.00

of the distributions themselves indicates that none of the distributions were markedly skewed to the extent that the hypothesis of normality in the parent populations could be rejected with confidence. Estimates of the population variance in terms of the following components were thus obtained: (1) variance attributable to sex differences, (2) variance attributable to motivational conditions, (3) an interaction variance between sex and motivational conditions, and finally (4) a within groups variance. The variances, the degrees of freedom, and the obtained *F*-ratios are persented in Table III.

Only the variances for the motivational conditions were significant (*F* of 4.11 being required for significance at the one percent level of confidence). These variances were significant in all of the three measures employed. All other variance ratios could be attributed to chance (an *F* of 3.99 being required for significance at the five percent level of confidence in each instance).

In addition to the variance analyses a *t*-test was carried out between the measures obtained for Groups I and IV. This test seemed legitimate in the light of the fact that an assumption of increasing response strength as a function of increasing hours of water deprivation was inherent in the design of this experiment. Utilizing the within groups variance as the best estimate of the population variance it was found that the hypothesis of a true difference between these two groups could be maintained at beyond

TABLE III

VARIANCE RATIOS, DEGREES OF FREEDOM, AND *F*'S FOR THE THREE EXTINCTION MEASURES, GROUP I–IV, EXPERIMENT I*

Measure	Variances	d.f.	*F*
	Motivational variance / Within groups variance		
Number	57.94/9.68	3/64	5.98
Time	52.60/11.36	3/64	4.64
Total Time	91258.13/9426.1	3/64	9.68
	Sex variance / Within groups variance		
Number	1.48/9.68	1/64	.15
Time	.26/11.36	1/64	.02
Total Time	16884.9/9426.1	1/64	1.79
	M × S variance / Within groups variance		
Number	1.47/9.68	3/64	.15
Time	2.05/11.36	3/64	.19
Total Time	15719.5/9426.1	3/64	1.67

* Within-groups variance has been used as the error term in each instance rather than M × S term as being a better estimate of the error variance (20).

the one percent level of confidence for all measures.[11]

The results of Group V, which may be considered as a control group, are reported in Table II. This group was extinguished under their original training drive (the relevant drive) and were not included in the analyses of variance reported above.

[11] The specific *t*-values for the various increases were as follows: number = 4.05 time door open = 3.50; total time = 5.15. The *t*-value used for the one percent level of confidence was taken as 2.898 for 17 d.f. It will be noted that neither the usual total $N - 1$ (the within groups variance being used as the error term) nor the $r(n - 1)$ d.f. were used but rather $n - 1$ was used in the light of heterogeneity of variance of the two groups. This should yield a rough test of differences between means regardless of the variances of the groups (20, p. 82).

DISCUSSION OF RESULTS

Taken in conjunction with the evidence that the degree of original learning (habit strength) may be assumed to be equal in the four experimental groups, the results of the extinction series strongly suggest that response strength does vary with changes in the intensity of an irrelevant drive. Such results are in accord with Hull's theoretical formulation.

A further consideration of the specific conditions of this experiment indicates that this effect on reaction tendency seems most reasonably attributable to the action of the irrelevant drive as a contributor to the strength of a 'generalized' drive state, *D*. It was noted in the introduction that an irrelevant drive could affect the response strength in two different ways: (1) as a contributor to the strength of the 'generalized' drive state, *D*, and (2) as a contributor to the effective habit strength through the conditioning of the stimulus component, S_D. The later role is obviated by the fact that the irrelevant drive was not present during training and hence could not have developed habit strength for the response.

Several points concerning the absolute amount of the response evocation may be noted. The results obtained from this experiment are not in agreement with those obtained by Koch and Daniels (13). It will be recalled that these investigators obtained results in the Skinner box which would indicate no response would be made by satiated animals. Of the hunger-thirst satiated animals of the present experiment, 14 of the 16 animals in Group I gave at least one response. Furthermore, it is of some interest to note that the results obtained from Group I in this experiment are quite similar to the findings of other investi-

gators (Zener and MacCurdy (25), Finch (7), Skinner (19), and Perin (16) so far as strength of response at zero relevant drive is concerned. It will be recalled that these experimenters found that the number of trials to extinction at zero relevant drive strength (further assuming water was present during this satiation period, the irrelevant drive of thirst should be approximately zero) varied between 17 and 28 percent of the number of responses at a relevant drive strength of 24 hours. The corresponding percent of response in the present experiment, based on a comparison of Group I and Group V, was 17 percent.

A comparison of the data of Group V with those of the other four groups provides confirmation of another prediction made in the introduction. Reference is made here to the theoretical implication that the response strength under an irrelevant drive would be less than that under comparable relevant drive strength (Corollary X of Hull). This loss would be ascribed to the change in the stimulus complex upon shifting of the motivation (and hence the stimulus drive complex) from hunger to thirst; to the consequent loss of the $s_D H_R$ component from the total habit strength; and to the reduction of the $s_{env} H_R$ component through the effects of afferent neural interaction.

A specific comparison may be made if we may assume that 22 hours of water deprivation produces at least as strong a value of primary drive strength, D, as does 22 hours of food deprivation. It will be seen from such an assumption that the prediction is amply supported by the experimental results. Group IV (irrelevant drive of 22 hours of thirst) required only about 50 percent as many trials to extinguish as did Group V (relevant drive of 22 hours of hunger).

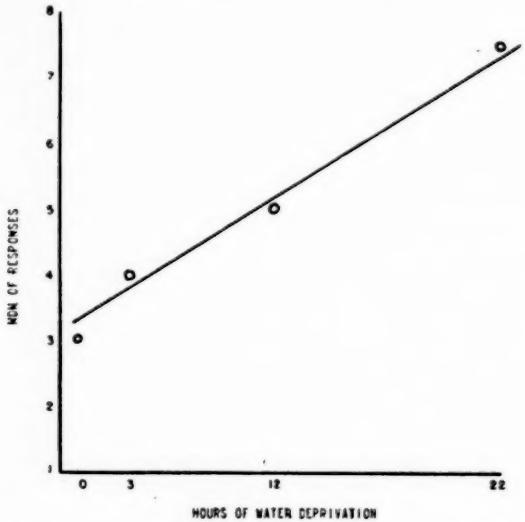

FIG. 3. A plot of the median number of responses made by the four groups of Experiment I which were extinguished under varying degrees of water deprivation. A straight line has been fitted to these data by the method of least squares and has been drawn in this diagram.

Most important, of course, is the question of the relationship between the strength of the irrelevant drive and the resultant response evocation. In an attempt to describe this relationship, the medians of the *N* measures have been plotted in Fig. 3 (a plot of the other measures obtained yields a similar relationship). In general there appears to be an increasing response tendency with an increase in the irrelevant drive. A linear relationship is indicated by the approximate fit of a straight line with the formula $y = 0.17x + 3.18$ (method of least squares).

A remaining possibility must be noted. It is felt, because of the presence of extremely deviating scores, that the median represents the more stable measure of the existing relationship. An examination of the means, however, reveals a slightly higher response evocation for the 3-hour group (Group II) than for the 12-hour group (Group III). Further, although an analysis of variance of the three groups of conditions of irrelevant drive (Groups II, III, and IV) yields an *F* approaching significance (motivational conditions/within groups variance = 2.22; *F* required for five percent level = 3.01), an assumption of equal response evocation for the three groups cannot be rejected at a high degree of confidence. From this evidence one might hypothesize that the motivational aspects of the irrelevant drive in this experiment were equal in their effect on response evocation and that the values of responses obtained at 3, 12, and 22 hours of irrelevant drive states were chance fluctuations about a common mean. It would be assumed under this hypothesis that the particular satiation procedure which was used would render ineffective the drive differences produced by the differential deprivations of water prior to satiation. Such reasoning would imply that the animals in each group would eat dry food which would increase the thirst drive. Eating would continue in each group until this thirst drive was at some maximal point (equal for all groups) at which time eating would cease. All groups under this assumption would be under a strong and equal thirst drive during extinction.

Speculative 'explanations' for the results may be numerous. It is possible to suggest a 'confusion theory,' i.e., an inability to clearly discriminate between the drive states of hunger and thirst as motivating conditions. This seems highly unlikely in view of the work by Hull (9), Leeper (15), Kendler (12), and others. A tempting explanation would be the suggestion that this behavior was a function of the unsatiated hunger drive rather than a function of the thirst drive when it is observed that only approximately 60 percent of the daily diet of food is eaten under conditions when the animal is deprived of water.

These theories, however, would be well termed speculative. They may serve as leads to further research, but their existence must be dependent upon such research in terms of manipulation of definable environmental conditions. The author is content for the present to state his conclusions in the frame work of Hull's hypothesis of a 'generalized drive state' being 'contributed to' by the irrelevant drives (defined by deprivation time) operative at the time and stating tentatively that the response measure will, within the range of deprivation times used, be approximately a linear function of the magnitude of these drives.

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AN EXPERIMENTAL TEST OF A TWO-FACTOR THEORY OF INHIBITION

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The present paper represents an attempt to extend the concepts used by Hull (4) in his explanation of such conditioning phenomena as extinction and spontaneous recovery to the explanation of certain phenomena of motor learning.[1] This extension seems possible and reasonable in view of the fact that the independent variables in terms of which these constructs are defined are the same as those known to be important in motor learning; namely, amount of work and time allowed for rest.

Following the lead of Hull, then, let us assume that the consistent superiority of distributed over massed practice in learning results from the development during unspaced practice of an inhibitory potential (I_R), the effect of which is to reduce the work-output of the organism. Let us further assume that this total inhibitory potential is made up of two more elementary decremental components, reactive inhibition (I_R) and conditioned inhibition ($_SI_R$). The two inhibitory factors are alike in that they both depress the habit but beyond this, the hypothetical properties assigned them differ.

Reactive inhibition is essentially a negative drive state closely allied to pain avoidance. It is a *response produced* inhibition which results from or accompanies all effortful behavior whether reinforced or not and dissipates during periods of rest. In this respect I_R resembles fatigue. If the rest periods in the work situation are too short to allow for the dissipation of the majority of the reactive inhibition developed (as in the case of massed practice learning), I_R accumulates and there develops an increasingly strong tendency (need) for the organism to cease work or rest. Sooner or later the resting response occurs and, when it does, a part of the reactive inhibition disappears. This dissipation of I_R serves as a drive reduction, reward or reinforcement.[2]

Since pauses, however slight, serve as reinforcements, it follows that the response of resting will become conditioned to whatever stimuli are present in the learning situation. This conditioned resting response tendency is conditioned inhibition ($_SI_R$), the second inhibitory component represented in the total inhibitory potential. The two inhibitory components are then, a drive (I_R) and a habit ($_SI_R$) which are intimately interrelated in that the drive component provides the motivational basis for the development of the habit. If our statement of these relationships is correct, I_R and $_SI_R$ must have all the characteristics respectively of other drives and other habits. The particular distinguishing charac-

[1] A similar attempt has recently been made by Ammons (1, 2). Although they are represented by different symbols, the constructs are almost like those used by Hull in terms of their definition and postulated effects on behavior.

[2] The term, resting response, may appear self-contradictory to some readers. To the author, however, the term seems quite appropriate. As used in this paper, resting is thought of as active, motivated behavior which is a goal response and reduces the drive I_R. In this sense, the resting response must be distinguished from the cessation of activity which results from neuromuscular impairment. The physiological accompaniments of I_R and of the response of resting are not known.

teristic with which this paper will concern itself is the course of development of the two separate inhibitory potentials.

Since conditioned inhibition is a habit, it can show, following Hull's theory, only one type of development. It must be a positive growth function of the number of reinforcements. Reactive inhibition, by contrast, is a drive. This would suggest that, as the organism goes on working without rest, the amount of I_R might be expected to accumulate as some increasing function of the amount of effort previously expended.

If the organism could somehow be induced to go on working for a fairly long period *with no rest whatever*, this formulation might actually work. In practice, however, such a state of affairs probably never obtains. Since I_R is a drive, it seems only reasonable to suppose that the accumulation of a certain critical amount will automatically produce resting. When this happens, the amount of I_R will decrease as a function of the length of the period of inactivity and of the amount of I_R present prior to the rest. Presumably, once I_R is reduced to below the critical level, the organism driven by motivation to perform the task at hand will resume work and continue working until the critical level of I_R is reached again. Then it will rest, reducing I_R; start work again, increasing I_R and so on. What will eventually happen is that a state of equilibrium will be reached in which the organism rests long enough to keep I_R at or slightly below some constant specific level.

At this point, the question may be legitimately raised as to what variables are involved in determining the amount of I_R which must be accumulated before resting occurs. Since I_R is a drive which acts antagonistically to the other drives in the learning situation, it seems logical to assume that the greater the motivation driving the subject to learn the task at hand, the greater the amount of inhibition which must be accumulated to produce the resting response. This would also lead to the prediction that any factors tending to reduce the motivation of the subject will decrease the critical value of I_R necessary to produce resting. In motor learning experiments, evidence of decreasing motivation late in learning is to be found in the feeling of monotony reported by many *S*s. Our reasons for identifying this feeling of monotony with decreasing motivation may require further analysis. At the beginning of the learning session, a need to master the motor task is set up in the *S* by the *E*'s instructions. Accomplishment must, therefore, be considered as a consummatory behavior which reduces the strength of this motivation. As learning progresses, *S* will gradually approach a level of performance so great that the need for accomplishment or improvement is satiated. As this occurs, a larger and larger part of the *S*'s motivation disappears. He continues to perform because of auxiliary needs to comply with the explicit and implicit dictates of the *E* and of the experimental situation. But his active interest in the task is diminished. This he reports as a feeling of monotony or boredom.

If, as our previous analysis suggests, greater amounts of I_R will be tolerated by the highly motivated *S* than by the poorly motivated one, we would be led to predict that, late in learning, less I_R will be present and that its complete dissipation will produce less reminiscence than early in learning. Such a decrease in the amount of reminiscence is to be found in the experimental results reported by Ammons (2). Further evidence on this point will be presented later in this paper.

In addition to the differences in their postulated courses of development, sI_R and I_R differ in their degree of permanence. Conditioned inhibition is a habit. As such, it will show almost no diminution with the passage of time. The

drive character of I_R, however, means that reactive inhibition is reducible by the appropriate goal response, resting. The best available evidence (2, 6) indicates that, for some tasks at least, complete dissipation of I_R occurs within a few minutes. It is this difference in the permanence of I_R and ${}_sI_R$ that makes it possible to trace the course of their development independently.

The difference between learning curves for the same task obtained under conditions of massed practice in one case and distributed practice in another case may be thought of as representing the total amount of inhibition present in the massed practice learning situation. Also represented by this difference are the permanent ${}_sI_R$ and the reducible I_R. At any point in the learning process after the beginning of practice it should be possible to separate the I_R and ${}_sI_R$ components by the introduction of a rest period. During such a rest, reactive inhibition would be expected to dissipate. As a result, when learning is resumed, theoretically there should be an increase providing a measure of the amount of I_R present prior to the rest. The level of performance after rest should not, however, equal or surpass that of a spaced practice group which has been given an equal number of learning trials. Since ${}_sI_R$, as a habit is permanent, it would be unaffected by the rest and still operate to depress performance when learning is resumed. The amount by which the reminiscence point is still below the spaced practice curve should, therefore, provide a measure of the magnitude of conditioned inhibition. If the difference between the massed and spaced practice curves is split into two portions in this fashion after several different amounts of practice, we should be able to trace the development of I_R and ${}_sI_R$ independently.

On the basis of the previous theoretical discussion and the methodological outline above, we are now in a position to make two predictions about the courses of development of the indices of I_R and ${}_sI_R$:

1. The index of reactive inhibition will show a rapid increase during the early learning trials, attain a constant level and perhaps show some decrease late in learning as a function of decreasing motivation.

2. The index of conditioned inhibition will increase as a negatively accelerated (habit) function of the amount of practice.

The present investigation was specifically designed to test these two predictions.

Experimental Procedure

The learning task chosen was the alphabet printing task previously used by Kientzle (5) and described by Ruch and Warren (7) in which the *S* prints the alphabet upside down beginning at the right side of the page and working to the left. When the page upon which the *S* works is rotated 180 degrees, the alphabet appears correctly oriented. Each *S* was provided with four pages of forms mimeographed with spaces for 40 trials, allowing one in. of space per trial and ten trials per page. The format was essentially the same as that presented by Ruch and Warren. The four pages were stapled together which meant that the *S* was required to turn a page after trials 10, 20, and 30.

The experiment was administered to 30 to 50 *S*s at a time following a procedure which included these five general steps:

1. The experiment was presented as an original investigation in which the *S*'s cooperation was requested to the extent of his asking no questions.

2. A brief demonstration of the learning task was presented.

3. Specific instructions were given to work as fast as possible and to begin each new trial with the letter of the alphabet following the one with which the previous trial had been completed.

4. The details of the procedure for the particular group being run were outlined.

5. Any questions that did not reveal the intention of the experiment were answered by repeating appropriate parts of the instructions wherever possible.

When these preliminary instructions had been completed, the *S*s began work at the signal 'go.' In the case of all groups except the spaced control group, the *S*s were told 29 sec. after the beginning of each trial to go on to the next trial. The specific instruction was: "Go on to trial — [giv-

ing the number of the next trial]." This instruction was given during the thirtieth sec. of one trial and the first sec. of the succeeding trial. Since the *Ss* did not stop work for these two sec, the trials may be considered as an average of 30 sec. long. On trials 10, 20, and 30, after 27 sec., the instruction was: "Turn your pages and. when I say 'go,' go on to trial — (11, 21, or 31)." Six sec. were lost in this process, three from each of the trials involved. In the case of the spaced control group, where a rest was given between trials, a simple 'stop' and 'go' set of signals was used.

Following the procedure described above, 40 30-sec. trials were administered. In all, eight conditions were used in the experiment, two control conditions and six experimental. The two control conditions were a massed practice condition in which the 40 trials followed one another with no interval between them and a distributed practice condition in which the 30-sec. trials were separated by 30-sec. rest pauses. The 30-sec. rest interval was chosen after examination of Kientzle's results had indicated that, for one-min. trials, optimal distribution was achieved with 45-sec. rests between trials. It is a well-known fact that shorter work periods require shorter intervening rests for the occurrence of optimal performance.

The six experimental groups worked under massed practice conditions except that once during the experimental session a 10-min. rest was allowed. For the six different experimental groups, the rests came after trials 5, 10, 15, 20, 25 and 30. The interval of 10 min. was as long as could be allowed within the established laboratory schedule. While a longer interval might have been desirable, it was assumed that maximal recovery from inhibition would be very nearly complete within 10 min. The pursuit rotor studies of Ammons (2) and of Kimble and Horenstein (6) support this contention to some extent. Following the rest, the *Ss* began their first post-rest trial with the letter 'A' and then proceeded as before the rest period.

Except for the two control groups, all *Ss* participated in the experiment as a part of their regular elementary psychology laboratory. The control groups were recruited from a class in social psychology. A total of 474 *Ss* provided usable data in the experiment. Their distribution among the various conditions is shown in Table I.

At the conclusion of the experimental session, the *Ss* were asked to note on the back of their work sheets any pencil difficulties or other factors which might have interfered with their performance. They were also asked to report any failure to follow instructions. Such *Ss* (about 10 percent of the total) were discarded.

TABLE I

DISTRIBUTION OF SUBJECTS AMONG THE VARIOUS EXPERIMENTAL CONDITIONS

Experimental Condition	*N*
Massed Control	50
Spaced Control	46
Rest after Trial 5	54
Rest after Trial 10	58
Rest after Trial 15	69
Rest after Trial 20	65
Rest after Trial 25	66
Rest after Trial 30	66
Total	474

RESULTS

The experimental procedures outlined in the preceding section were designed to do four things: (1) the performance of the massed control group was intended to show the course of learning under conditions in which the decremental factors are allowed to operate to the fullest extent; (2) the spaced practice control group was run to show the course of learning under conditions in which work decrement is kept at a minimum; and six experimental groups were treated in such a way as to show (3) the increase in work output after a rest and also (4) the difference between the post-rest score and the performance of the spaced practice group after a similar number of practice trials.

The basic data obtained from the eight groups are shown in Fig. 1. Here the results for all groups are presented graphically. The spaced practice curve is simply a plot of the mean score on each 30-sec. trial for the spaced practice group. In plotting the massed practice curve, trials 2, 3, 4, 10, 11, 20, 21, 30, and 31 were omitted. Trials 2, 3, and 4 were omitted because it was apparent that many of the *Ss* became confused on these trials and had trouble making the transition from trial to trial. The

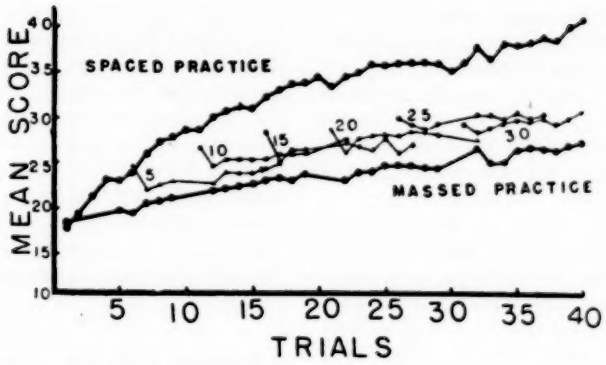

FIG. 1. Graph of the basic data of the experiment. The upper and lower curves show performance of the spaced practice group and of the massed practice group. The intermediate functions show the post-rest performance of the six experimental groups after a 10 min. rest. The number on each of these curves is the number of the trial after which rest was given. N for the various trial-segments of the massed practice curve is as follows: trials 1–5, 428; trials 6–9, 374; trials 12–15, 316; trials 16–19, 247; trials 21–25, 182; trials 26–29, 116; trials 32–40, 50. For the spaced practice curve, $N = 46$.

result was that they showed a decrease in performance which lasted until trial 5. The other trials were omitted because these trials were, on the average, three sec. shorter than the others, the three sec. being used to turn pages. The points on the massed practice curve represent all of the usable data obtainable from the appropriate experimental groups; i.e., data from the experimental groups *prior to the rest period* are included. It is only from trial 32 on that the data are only those from the massed practice control group. As is usually the case in motor learning experiments, the spaced practice curve is much superior to the massed practice curve.

The shorter functions plotted between the massed and spaced practice curves show the performances of the individual experimental groups after the rest. Only the first 10 points after rest are plotted in order to keep the graph readable. There are several features of particular interest. The first of these is that each group shows a marked increase in performance (reminiscence) after the rest. Table II presents the difference between the mean pre-rest and post-rest scores (increase) for each of the six experimental groups, together with a critical ratio computed in such a way as to test the hypothesis that the population increase is zero. All of the increases are found to be highly reliable.

A second interesting feature is the marked drop in performance after the first post-rest trial. What this drop probably indicates is that reactive inhibition develops more rapidly than

TABLE II

MEAN INCREASE FOR EACH EXPERIMENTAL GROUP TOGETHER WITH A CRITICAL RATIO

Trial After Which Rest was Given	Mean Increase	*CR*
5	5.28	10.59
10	5.93	11.63
15	5.96	13.42
20	3.83	8.17
25	4.76	10.48
30	4.08	7.73

habit. As a result, instead of improvement in performance immediately after rest, a decrease occurs.

It will in this connection be noted that there is no evidence at all for the warm-up phenomenon demonstrated by Ammons (2) for pursuit rotor learning.

Reference again to Table II will serve to make a third important point; namely, that the amount of reminiscence does not seem to be very much different from group to group. There is, however, some suggestion of a tendency for the groups whose rest was postponed the longest to show the least reminiscence. A similar phenomenon appears in one of Ammons' graphs (2, p. 402).

Turning now to the matter of the amount by which the reminiscence points fall below the spaced practice curve, we note in Fig. 1 and easily discernible tendency for this difference to increase with the amount of practice. The point for the five trial group is slightly above the spaced practice curve. The points for groups whose pre-rest work period was longer fall progressively further below the spaced practice curve. A clearer picture of this relationship appears in Fig. 2 where the difference between the reminiscence point and the spaced practice curve is plotted as a function of the number of trials before rest was given. The result is an increasing function which shows some tendency toward negative acceleration.

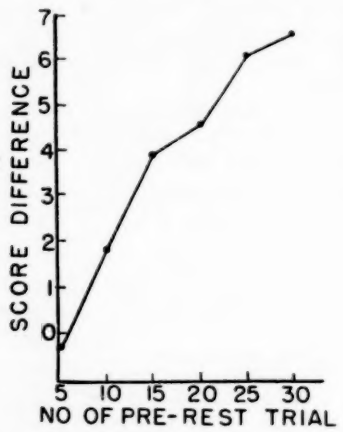

FIG. 2. Graph showing amount by which the spaced practice group exceeds the reminiscence point after six different amounts of practice

DISCUSSION

As a first step in attempting to relate the experimental results to the theoretical formulation outlined in the introduction, it is necessary to ask the question whether or not the difference between the distributed practice and massed practice curves presented in Fig. 1 actually represents something like the total amount of inhibition that can be developed in 40 30-sec. learning trials on this particular task. Some evidence on this point can be obtained through a comparison of the present results with those obtained by Kientzle (5). During the final minute of practice, Kientzle's most efficient group printed an average of 72.5 letters. The spaced control group of the present experiment during a comparable period of time (the last two trials) printed 81.5 letters. The difference of nine points may presumably be taken as evidence that the use of 30-sec. trials rather than one-min. trials kept inhibition at very near a minimum. The massed practice control group of the present experiment printed a total of 54.7 letters in the final minute of practice. This is to be compared with a mean score of 51.2 letters printed by Kientzle's massed practice group. This indication is that, here, the two groups are comparable, especially since Kientzle found that the introduction of a three-sec. pause between trials raised the final

mean score to 58.7 letters. In other words, the massed practice group in the present experiment worked under conditions of very nearly maximal inhibition, while for the spaced practice group inhibition was near a minimum.

Because of this latter point, we may now concern ourselves with the question of the nature of the function according to which the two components of total inhibition develop. To consider first the course of development of I_R, the position taken in the introduction was that the magnitude of this variable will remain constant for a time after the initial rapid development of a certain critical amount and then show a decrease. Reference to Table II shows that this postulation is, in the main, substantiated. The major point at which the prediction breaks down is that we have supplied no evidence for the initial rapid increase. Instead we find that after only 2½ min. of work the magnitude of I_R is almost as great as at any point in the learning process. Since I_R must have a zero value somewhere, this can only mean that the accumulation of I_R is extremely rapid. If we arbitrarily say that the maximum amount of I_R produced in this type of experiment has a value of 5.96 (the greatest amount of reminiscence obtained for any group) we find that the mean reminiscence score for the five trial group is 88 percent of this value or 5.28. This result represents a striking confirmation of Ammons' finding that three min. of work produced nearly as much reminiscence as eight min. where the maximal value was obtained. In this experiment the maximal amount of reminiscence occurs at 7½ min., and 2½ min. in the learning situation produces very nearly as much. In view of the similarity of these results to those of Ammons, it seems permissible to argue that, if shorter work periods had been sampled, we would have found, as he did, a rapid increase in the amount of reminiscence as a function of the amount of practice.

Further evidence of the extreme rapidity of the development of I_R is to be found in an unpublished experiment by Bilodeau (3). For some of his *S*s, the length of the trials on a motor learning task was 10 sec. For other *S*s, the trial was 30 sec. long. His results show a highly reliable difference between the two groups after only 30 sec. of work.

In Table II, a further point is made with respect to the course of development of I_R; namely, that late in learning the magnitude of this variable tends to decrease. Although the absolute magnitude of this decrease is not great, it cannot easily be considered as a purely fortuitous phenomenon, particularly in view of the fact that the same decrease was shown by Ammons to occur in pursuit rotor learning. As was suggested earlier, our present tentative hypothesis is that the decrease in I_R occurs because of a decrease in motivation late in learning. Although no quantitative evidence on this point is available, many of the *S*s used the words 'monotony' and 'boredom' in describing their reaction to the experiment, particularly in the later trials. If our earlier analysis of the motivational component in motor learning experiments is correct these comments are understandable as evidence of a decreasing need to perform the motor task.

Turning now to the development of the habit, $_sI_R$, a picture of how one measure of this variable increases with practice is presented in Fig. 2. There we see that the difference between the reminiscence point and the spaced practice curve increases as a function

of the number of pre-rest trials. It is of particular interest that, on trial five, the value of ${}_{S}I_{R}$ is essentially zero. Assuming that ours is an adequate measure of conditioned inhibition, it is apparent that the hypothesis that ${}_{S}I_{R}$ does not begin to develop until some critical value of I_R is reached is substantiated. After five learning trials, it will be recalled, I_R had reached a value beyond which no important increase occurred. The hypothesis that some threshold value of I_R is necessary to begin the process of development of ${}_{S}I_{R}$ would lead to the prediction that, early in learning (when I_R has not yet reached this value) no ${}_{S}I_{R}$ would be present. This prediction is substantiated by the curve of development of ${}_{S}I_{R}$ shown in Fig. 2.

Finally, it may be noted that the development of ${}_{S}I_{R}$ substantiates the postulation by Hull that one portion of total inhibition is a habit. At least Fig. 2 bears a resemblance to the type of curve obtained when the learning curve for a rapidly acquired habit is plotted. Although no asymptotic value has been reached in the present experiment, the tendency toward negative acceleration suggests that one would have been reached had measurements been made after longer period of work. Furthermore, on the basis of our analysis of the relationship between I_R and the other motivational elements of the motor learning situation, we are led to the prediction that the reaching of an asymptotic level of conditioned inhibition will be postponed. It was hypothesized that the development of ${}_{S}I_{R}$ depends chiefly upon the maintenance of some critical threshold value of I_R. When a certain magnitude of reactive inhibition is reached, the S rests and this resting response becomes conditioned to the stimuli in the learning situation. This means that any conditions which tend to reduce the tolerable amount of I_R will increase the amount of resting and, therefore, the rate of development of ${}_{S}I_{R}$. One such condition is the decreasing motivation which occurs late in learning. On this basis, our prediction is that, concurrently with a drop in the S's motivation, there will be an increase in the rate of development of conditioned inhibition. Such a relationship may be what is reflected in Fig. 2.

Summary

A total of 474 *S*s were run in an alphabet printing experiment with the end in view of testing a version of Hull's two-factor theory of inhibition modified to handle some phenomenon of motor learning. The most important deviation from Hull's formulation was the specific assumption that, after a short period of practice, the amount of reactive inhibition would attain a stable constant level which would be maintained until late in learning.

The experimental technique provided for learning under conditions of maximal inhibition in the case of one group of *S*s and under conditions of minimal inhibition in the case of another. This was accomplished by using highly massed practice and nearly optimal spacing for the two groups respectively. Six further groups of *S*s were run under conditions of massed practice except that they were allowed one 10-min. rest period during learning. For the six experimental groups, the rests came after trials 5, 10, 15, 20, 25, and 30 in a 40-trial series. The increase in performance after rest (reminiscence) provided a measure of reactive inhibition. The amount by which rest failed to increase performance to make it equal to that of the spaced practice group after

a similar number of trials provided a measure of conditioned inhibition.

Using these indices, it was shown that I_R remains relatively constant from trial 5 on through 15 and then begins to decrease. ${}_sI_R$, on the other hand, shows some tendency to develop as a negatively accelerated (habit) function of the number of trials as Hull's theory would predict.

The results, in the main, confirm those of Ammons for pursuit rotor learning except that no warm-up phenomenon was noted.

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PROACTIVE INHIBITION AS A FUNCTION OF TIME AND DEGREE OF PRIOR LEARNING

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I. Introduction

Proactive inhibition (PI) is defined as the decrement in recall of a task as a result of *prior* learning of other material. This phenomenon is to be contrasted with retroactive inhibition (RI) in which the decrement in recall is due to other material coming *between* original learning and the retention test. Though PI was discovered 20 years ago by Whitely (12), there has been so little experimental work concerned with it that it has not assumed a place of importance in forgetting theory that is commensurate with the position held by RI. Insofar as interference is accepted as a general causal mechanism in the production of forgetting, and insofar as it can be shown that PI results from interference between activities, it is essential that the variables causing this interference to vary be determined.

The following is a summary of present knowledge concerning PI.

1. No systematic study has been performed to determine the relationship between *similarity* of two tasks and PI. However, three separate experiments (1, 5, 11) suggest that, as in the case of RI, similarity is a major variable determining PI.

2. When *amount of prior learning* is defined in terms of number of prior lists, and when each successive list requires the learning of new responses to old stimuli, it has been shown that amount of PI increases directly as the number of prior lists increases (8). In this study it was also shown that the same relationship holds between RI and amount of interpolated learning, but that the absolute amount of RI was greater than amount of PI.

3. Both RI and PI can be produced after very short intervals of time, e.g., 10 sec., when the memory span technique is used (6).

4. Under comparable conditions, RI is consistently greater than PI for short intervals between learning and recall, e.g., 20 min. (3, 5, 8), but it may be inferred from two studies (9, 10) that there is little difference between the two forms of inhibition after much longer intervals, e.g., 48 hr.

5. The following factors have not as yet been experimentally manipulated in the PI situation:

(a) The degree of prior learning (with one exception which will be noted shortly).

(b) The degree of learning of the second task, i.e., the task to be recalled.

(c) The time interval between the learning of the two tasks.

(d) The time interval between the learning of the second task and its recall.

(e) The type of material, i.e., degree of meaningfulness, intra-task similarity, motor involvement, etc.

The present paper is a report of two experiments concerned with two of the above variables; namely, (1) degree of prior learning, and (2) the time between learning the second task and its recall.

One study has been performed in an attempt to determine the relationship between degree of prior learning and amount of PI, but the study is inconclusive because little PI was produced. This experiment, by Waters (11), utilized lists of 18 consonant syllables. Under six different experimental conditions the

* These experiments were made possible by a grant from the Ethel Dummer Fund, University College, Northwestern University.

prior list was given 1, 3, 5, 10, 20, or 40 repetitions before the second list was presented for five trials. Recall of the second list was taken after 20 min. The results showed little evidence of PI and no relationship was apparent between the little inhibition which was present and degree of prior learning. However, an inspection of the lists used by Waters (lists constructed by Melton and Irwin, 4) indicates that the similarity between lists was low. Specific interfering tendencies must have arisen largely from serial position identity, and this is known now to be an unfavorable situation for producing PI (3, 5). It remains to be shown what the relationship between PI and degree of prior learning is when PI is produced by setting up conditions in which interference is high.

No experiment has been reported concerning how the time interval between learning the second task and recalling it influences PI. Direct comparisons have been made between the recalls of two contiguously learned lists after five and 48 hr. (9), but since no control condition was used, absolute amounts of PI and RI could not be determined for the two time intervals. It was pointed out that the logic of the situation suggests that PI should increase as a function of time between learning and recall but no empirical verification has been attempted.

In addition to the systematic retention data which the present experiments were expected to yield, they provide also a test of the relative influence of response strength and passage of time in bringing about overt intrusions at recall. These variables (response strength and time) are presumed to be the two major factors influencing the degree of differentiation between lists (8), and degree of differentiation is presumed in turn to determine the number of intrusions. Differentiation increases as the difference in response strengths of the two lists increases, and decreases as the time between learning and recall increases. Low differentiation is a favorable condition for intrusions; high differentiation is an unfavorable condition. Both variables of which differentiation is suggested to be a function are manipulated independently in the present experiments.

II. Procedure

Subjects and materials.—College students served as *S*s, 24 in each of the two experiments. In each experiment *S* learned lists of paired two-syllable adjectives presented on heavy white tape by a Hull-type memory drum. Ten pairs of adjectives were used in each list. When two lists were learned under an experimental condition, the second list had the same stimuli as the first, but different responses. This is the traditional A–B, A–C paradigm which has produced high amounts of interference in both the learning of the second list and in recalling either list. The words were presented in three different orders within the lists to prevent serial learning. The drum was timed so that the stimulus word of each pair was exposed for two sec., following which the stimulus and response were exposed together for an additional two sec. Anticipation learning was used at all times. Eight sec. rest followed each trial.

Experimental design.—Table I shows the basic design of the two experiments. In each experiment four degrees of prior learning were used, the degree of learning defined by a performance criterion. On Cond. A, the control condition, no prior list was learned. On Cond. B, list A–B (prior list) was presented until three or more responses were anticipated correctly on a single trial. On Cond. C the list was presented until eight or more responses were correctly anticipated, and on Cond. D, *S* was presented the list until all 10 items had been anticipated correctly on a single trial and then five additional trials were given.

For all conditions the second (A–C) list was presented until six or more responses were anticipated correctly on a single trial. It is to be noted that the two experiments differ only in the length of the interval between the end of learning the second list and its recall. In Exp. I the interval was 20 min., while in Exp. II the interval was 75 min. In all conditions of both experiments *S* relearned the second list to a criterion of one perfect trial.

Each experiment contained four conditions. With 24 *S*s a complete counterbalancing of conditions is possible. The lists used on successive days were held constant. Two practice days preceded the four experimental sessions. On each of these practice days *S* learned two lists

TABLE I

EXPERIMENTAL DESIGN FOR DETERMINING THE INFLUENCE OF TIME AND DEGREE OF PRIOR LEARNING ON PROACTIVE INHIBITION

Condition	Learn A–B	Learn A–C	Rest Interval	Recall—Relearn
A	—	6 Correct	Exp. I: 20 Min.	A–C
B	3 Correct	6 Correct		A–C
C	8 Correct	6 Correct	Exp. II: 75 Min.	A–C
D	10 Correct Plus 5 Trials	6 Correct		A–C

and was given practice in recalling the second list after a short time interval. In Exp. I the 20-min. interval was filled with light reading, while in Exp. II *S* was dismissed for the 75-min. rest.

No instructions were required other than those commonly given for paired-associate learning. All possible precautions were taken at the time of recall to insure that *S* knew which list he was expected to recall. The A–B lists were always presented on the right side of the drum, the A–C lists on the left. At recall, *S* was instructed as follows: "We will now continue with the list you were working on just before the rest period. Be sure and give as many responses as possible on the first trial and continue with the list until you can say it perfectly."

III. RESULTS

Prior learning.—The mean number of trials required to reach the established criteria for the prior learning of the three experimental conditions of each experiment is shown in Table II. The mean number of correct responses on the criterial trial of each condition is also shown. These data demonstrate the equality of the learning ability of the two groups of Ss used.

TABLE II

MEASURES OF DEGREE OF PRIOR LEARNING
N is 24 in each experiment.

Condition	Exp.	Trials to Reach Criterion		Correct Responses on Criterial Trial	
		M	σ_M	*M*	σ_M
B	I	4.33	.48	3.50	.15
	II	4.42	.48	3.83	.22
C	I	11.54	1.45	8.13	.10
	II	11.25	1.28	8.33	.13
D	I	20.71	1.66	9.58	.19
	II	19.92	1.23	9.79	.09

Second-list learning.—Table III shows the level of learning attained on the second lists and the number of trials required to attain it. The criterion for each condition was six correct responses on a single trial. It is noted that the data in Table III show that in general as the degree of prior learning increases the rate at which the second or A–C list is learned be-

TABLE III

MEASURES OF DEGREE OF SECOND-LIST LEARNING

Condition	Exp.	Trials to Reach Criterion		Correct Responses on Criterial Trial		Total Correct Responses	
		M	σ_M	*M*	σ_M	*M*	σ_M
A	I	6.92	.70	6.79	.17	21.63	2.13
	II	6.50	.69	6.33	.14	19.21	1.91
B	I	6.38	.52	6.58	.18	18.79	1.37
	II	7.54	1.29	6.92	.18	21.29	3.40
C	I	5.46	.39	6.71	.20	17.58	1.54
	II	5.67	.58	6.75	.19	17.71	1.89
D	I	4.92	.31	6.67	.17	16.42	1.20
	II	5.04	.46	6.71	.23	15.33	1.12

comes faster. This associative facilitation is clearly evident in the first column (trials to reach criterion) except in the case of Cond. B, Exp. II. The data for this condition are somewhat out of line with those of other conditions both with respect to mean measurements and to the errors of those means. These deviations are caused mainly by two *S*s who took considerably longer to learn under this particular condition than under the others. There is no explanation for this so far as the conduct of the experiment is concerned. Differences in the number of correct responses on the criterial trial (as shown by middle column of Table III) will be adjusted by determining the mean loss over the rest interval, i.e., by subtracting the recall of each *S* from the number of correct responses on the criterial trial of the second list.

Associative inhibition in learning the second list.—Table III has shown that in general as the degree of prior learning increases, facilitation in learning the second list increases. This facilitation is not evident at all stages of learning. In order to show this by detailed analysis, the data for both experiments have been combined, since the conditions of the two experiments are exactly the same up to the point of the introduction of the rest interval. *N* thus becomes 48 in all calculations.

If associative inhibition is present in experiments like the present one it will be found on the first anticipation trials of the second list. The data for the first two anticipation trials (trials 2 and 3), along with the mean trials to reach the criterion, are shown in Table IV. Conds. B, C, and D are compared with A to determine the amount of facilitation or inhibition. With 48 cases a *t*-value of approximately 2.6 may be taken as significant at the one percent level of confidence. The data show that significant associative inhibition is produced on the first two anticipation trials of the second list when the degree of prior learning is low. With a high degree of prior learning, no measurable inhibition is present on the first anticipation trial, while *significant positive transfer or associative facilitation is present on the second anticipation trial.* These relationships are shown graphically in Fig. 1. It is apparent that not only are positive and negative transfer a function of degree of prior learning, but are also subject to marked shifts in amount as a function of the stage of learning the second list.

The facilitating effect on the second list of high degrees of prior learning poses the same problem as did a previ-

TABLE IV

ASSOCIATIVE INHIBITION AND FACILITATION AS A FUNCTION OF DEGREE OF PRIOR LEARNING

	Conditions								*t*-Values		
	A		B		C		D				
	M	σ_M	*M*	σ_M	*M*	σ_M	*M*	σ_M	A vs. B	A vs. C	A vs. D
Trial 2	2.08	.22	1.29	.18	1.67	.18	2.00	.20	3.16	1.58	.31
Trial 3	3.25	.31	2.44	.24	3.60	.28	4.19	.27	2.61	1.09	3.13
Trials to Criterion	6.71	.49	6.96	.69	5.57	.35	4.98	.28	.37	2.15	3.68

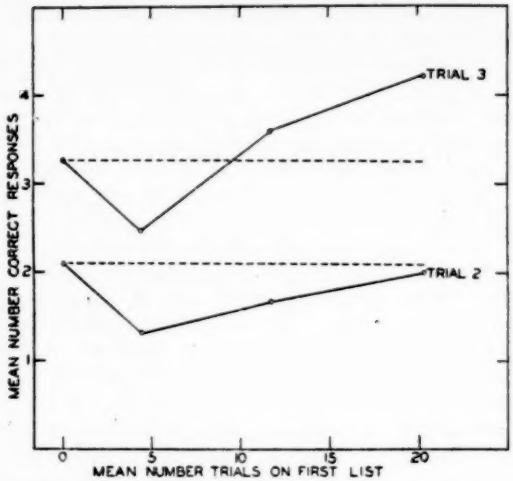

FIG. 1. Associative inhibition and facilitation on the first two anticipation trials as a function of degree of prior learning. For each trial the area below the dotted line is indicative of inhibition; the area above the line, facilitation. N is 48 for each point.

ous study in which the *number* of prior lists was varied (8). The effect of either method of varying prior learning results in the second list being learned with different speeds to the same criterion. Other things being equal, the faster the learning the slower the forgetting. In the previous study it was shown by item analyses that this more rapid rate of learning did not prevent inhibition from occurring at recall. However, it is very likely that in that study as well as in the present one, the absolute amount of PI is underestimated. That is, if it were possible to remove the facilitating effect in learning the second list when the degree or amount of prior learning has been high, the measured PI would be greater.

It may be said that there appears to be no way in which the facilitating effect of high degrees of prior learning on the learning of the second lists can be removed within the general experimental design used here. During the learning of the second list there are three identifiable factors operating: (1) interference effects of A–B on A–C; (2) general practice effects of learning how to learn; and (3) specific facilitating effects produced by the reduction of stimulus generalization as a consequence of the prior learning (2). The first factor must be present necessarily if PI is to be produced at recall. The influence of the second factor, which is probably not great because of the four practice lists, could be reduced further by giving more practice days. The third factor could be eliminated by using completely different stimuli in the second list but if this were done the interference effects would be lost. This is a rather strange state of affairs, in that if we eliminate a condition which produces positive transfer we will at the same time be eliminating a condition which produces negative transfer. If a method is devised for eliminating the generalization among stimulus

items before the experiment starts, it is possible that the A–B, A–C paradigm could be used without producing greater facilitation in learning A–C as the degree of learning of A–B increases.

Proactive inhibition at recall.—The mean number of correct responses recalled on each of the four conditions of both experiments is shown in Table V. Also shown is the mean loss occurring between the last trial of learning the second list (as shown in the middle column of Table III) and the recall of that list. The *t* ratios were determined by direct comparison for each *S* of the mean loss between Cond. A and each of the other three conditions. Thus, for Cond. A, Exp. I, the mean loss was 2.04, and for Cond. B the mean loss was 2.41. The difference between the two, .37 ± .48, gives a *t* of .77. With 24 *S*s there are 23 degrees of freedom, and a *t* of 2.81 is significant at the one percent level of confidence.

As indicated in Table V, significant amounts of PI were produced by the degrees of prior learning used on Conds. C and D when retention was measured after 20 min. Cond. B showed a greater loss than the control condition but the difference is far from being statistically significant. These results are highly similar to those obtained for RI when measured after 20 min. (7). The general function appears to be the same whether we are measuring RI or PI, though the absolute amount of RI is greater than the absolute amount of PI.

TABLE V

PROACTIVE INHIBITION IN THE RECALL AFTER 20 MIN. (EXP. I) AND AFTER 75 MIN. (EXP. II)

Condition	Recall		Loss		*t*
	M	σ_M	*M*	σ_M	
Exp. I					
A	4.75	.33	2.04	.29	—
B	4.17	.32	2.41	.32	.77
C	3.33	.36	3.38	.32	3.09
D	3.33	.28	3.34	.32	3.15
Exp. II					
A	2.54	.33	3.79	.34	—
B	2.67	.27	4.25	.34	1.12
C	2.38	.29	4.37	.31	1.45
D	1.67	.24	5.04	.28	2.78

When PI is measured after 75 min. (Exp. II) the data show that only Cond. D (high degree of prior learning) produced significant PI. The PI on Conds. B and C is not statistically significant. The data as a whole in Table V superficially suggest that PI decreases as the time between learning and recall increases. Cond. C provides the only evidence for suggesting such an interpretation. If we plot the loss for each condition for both time intervals we come to the more likely conclusion that PI remains relatively constant between 20 min. and 75 min. Such an interpretation is indicated by the smooth curves drawn in Fig. 2. The curves are well within the error ranges of all empirical points and are offered as the best estimate of the relationship between PI and time and degree of prior learning.

Relearning.—*S*s relearned the second list to one perfect trial under all conditions. As in other experiments on PI, the present relearning scores show PI to be extremely transitory. On the second trial there was some evidence of PI but none of the differences approached statistical significance. In the trials required to relearn the list there was no evidence for facilitation such as was present in original learning of the second list following a high degree of prior learning.

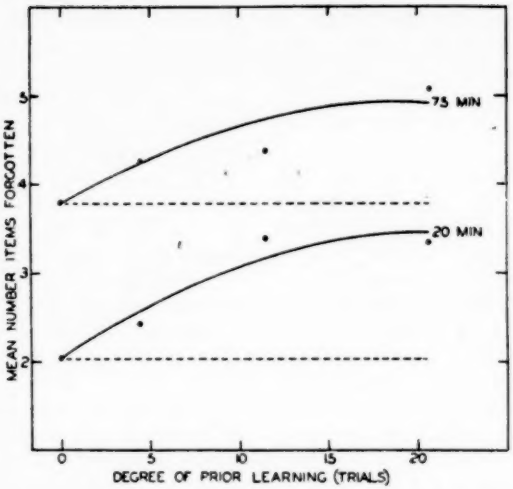

FIG. 2. Proactive inhibition as a function of time and degree of prior learning. The dotted lines indicate the amount forgotten without prior learning.

Intrusions.—Intrusions occurring during relearning are shown in Table VI. These intrusions are cases in which the *B* response from the first list occurred in the place of the *C* response of the second list during relearning. Two facts are fairly clear from the data: (1) on the first relearning trial the greatest number of intrusions occurred when the second list was moderately stronger than the first (Cond. C), with fewer intrusions occurring when the difference in the response strengths of the two lists was greatest (Cond. D); and (2) the greater the interval between learning and recalling the second list, the greater the number of intrusions.

Two additional findings concerning the intrusion data should be noted. First, there is little difference between experiments with regard to number of intrusions occurring *after* the first recall trial. This suggests that the influence of the time interval in producing intrusions is very transitory. The second finding is that in Exp. II the difference in number of intrusions

TABLE VI

TOTAL FREQUENCY OF OVERT INTRUSIONS OCCURRING ON THE FIRST RECALL TRIAL AND ON ALL OTHER RELEARNING TRIALS

Condition	After 20 Min. (Exp. I)			After 75 Min. (Exp. II)		
	1st Recall Trial	All Other Trials	Total	1st Recall Trial	All Other Trials	Total
B	3	4	7	6	2	8
C	13	9	22	22	12	34
D	1	5	6	21	3	24
Totals	17	18	35	49	17	66

on Conds. C and D is negligible on the first recall trial. This indicates that the time interval is more important than degree of learning in producing a decrease in differentiation, even though the influence of that time interval is transitory.

IV. Discussion

In a previous paper (9) it was argued that PI should increase as a function of time between learning and recalling the second list, since no PI is found after eight sec. (the usual inter-trial interval) whereas it does occur after 20 min. However, the implication of the present data is that between eight sec. and 20 min. PI reaches a given level and remains relatively constant up to 75 min. There is still a strong likelihood that PI will be shown to increase with much longer intervals than those used here. Such an expectation would be based on the fact that associative strengths of first-list responses recover with passage of time, maximum recovery taking place after much longer intervals than used in the present experiment. Thus, in a previous study (10) it was shown that the point of greatest recovery of the first list occurred after approximately 24 hr. when both lists had been learned to a criterion of one perfect trial. The net effect of this recovery is to increase the degree of first-list learning, a condition which has been shown here to increase PI.

The present data show that as degree of prior learning increases, amount of PI increases. This is what has been found for degree of interpolated learning and RI, except that the absolute amount of RI is greater than amount of PI. With longer time intervals between learning and recall, e.g., from 24 to 48 hr., it is likely that the absolute amount of PI and RI would be much the same, since with the type of materials used here, RI is likely to *decrease* with the passage of time and PI either increase or remain relatively constant (9). The changes in both RI and PI result from recovery of first list responses with passage of time.

The obtained relationship between number of intrusions and relative response strengths of the two lists is much the same as found previously in two separate studies on RI as a function of degree of interpolated learning (7, 8). The greatest number of intrusions in these previous studies occurred when the interpolated learning was moderately stronger than the original. Few intrusions occurred when the interpolated material was learned to a high degree, even though RI was great. As a result of these findings it was suggested (8, p. 25) that the amount of differentiation between the two lists changes as the second list is learned. Furthermore, it was suggested that this differentiation develops as a slowly rising positively accelerated function of the number of trials on the interpolated list. In the earlier study the degree of first-list learning was held constant in all conditions so that variations in its level of learning did not enter into the original postulation. The present data now make it clear, however, that differentiation cannot be considered without reference to degree of learning on the first list; hence, further elaboration is required.

Differentiation may be thought of as the degree of discriminability between two response systems which exists at the time of the recall of either. Amount of differentiation is presumed to be a function of time between learning and recall and a function of relative response strengths of the two lists. Differentiation changes, of course, during the learning of the

second list, but level of differentiation attained at the end of the second-list learning can be predicted only by referring to the level of learning of the first list relative to that of the second. We will first interpret the results of Exp. I within this framework.

With a very low degree of learning of the first list (as on Cond. B), differentiation at the start of the second-list learning would be low and would remain so until the second list becomes considerably stronger. However, the second list on Cond. B is taken to a criterion of learning which may be described as being only moderately stronger than the first list. Thus, differentiation would be quite low. On Cond. B there are few intrusions and there is little PI. Even though differentiation is low on this condition the response which is moderately stronger than its competitor is the correct response—the response from the second list. With low differentiation the obtained response is determined largely by sheer associative strength. If, under these same conditions, the first list was being recalled as in an RI paradigm, we would expect many intrusions and considerable RI.

On Cond. C of Exp. I, where second-list learning was terminated at a level somewhat below that of the prior list, differentiation would be low and the responses obtained at recall on the basis of associative strength would be those from the prior list. Thus, we would expect many intrusions and considerable PI, as was the case. On Cond. D, differentiation would be high as a consequence of the wide disparity in response strengths and we would expect few intrusions. Large PI on this condition is attributed to the fact that at the time of recall *S* perceives the dominant response tendency as being from the first list and hence incorrect. *S* thus rejects this response but the rejection process does not allow time for him to think of the correct (second list) response even if it were available. *S*s report such experiences. The implication of this 'lack of time' hypothesis is that in both the RI and PI paradigms an increase in the time permitted for anticipation would decrease RI and PI when response-strength disparity is large between the two lists.

Exp. II, when compared with Exp. I, shows clearly the influence of the passage of time on differentiation. Many more intrusions occur at recall in Exp. II than in Exp. I. Differentiation thus decreases as some function of the interval between learning and recall. It is presumed that if zero differentiation existed before a rest interval, time would be an unimportant variable. It is further presumed that the higher the differentiation before a rest interval (as on Cond. D) the more important will be the passage of time in reducing differentiation. This is inferred from the fact that on Cond. D, Exp. II, the number of intrusions on the first recall trial is nearly as great as for Cond. C. Roughly, the passage of time from 20 min. to 75 min. brings a twentyfold increase in the number of intrusions for Cond. D, while only a twofold increase for Cond. C.

It should be noted that differentiation is postulated to be low when two response systems are of near equal strength. Undoubtedly, further elaboration of this point will be required in that absolute strength will have to be considered. It is likely, for example, reasoning from Gibson's theory (**2**), that two lists having 20 trials each will be more highly differentiated than will two lists having five trials each.

Mention should be made of the present use of the concept of differentiation as related to the use of the same concept by

Gibson (2) in an earlier publication. Gibson has used the concepts of generalization and differentiation (reduction of generalization) to explain a wide variety of learning and retention phenomena. In her formulation, however, she has not incorporated the A–B, A–C situation; rather, she has formulated her predictions on the basis of similar stimuli. The only mention made of the identical-stimulus paradigm is her reference to the idea that decreased stimulus generalization makes for positive transfer in learning the second list. She indicates, however, that this positive transfer would be counteracted by interference, because of 'interlist conflict of responses' (2, p. 222). Since it seems clear that factors making for negative transfer are also going to be factors influencing the recall of either list, Gibson's failure to integrate completely the A–B, A–C situation into her otherwise extremely useful system is a serious omission.

It would appear that the use of the term differentiation in the present context is very much the same as the use of the term by Gibson in explaining interlist effects. In both cases differentiation is said to be a function of degree of learning and passage of time. There seems to be no reason why the A–B, A–C situation cannot be considered on the same dimension as *similar* situations by assuming that identity represents maximum similarity. In such cases generalization as far as the stimulus symbols *per se* is concerned would be complete when moving from the first list to the second. However, other features of the situation may 'be used' for differentiating purposes. For example, the second list may be learned on the opposite side of the drum from the first list; the posture of *S* changes; the fact that it *is* a second list probably adds a discriminating factor, etc. With such assumptions the present use of the term differentiation is highly comparable to Gibson's earlier use of the term and we may speak of decrease in differentiation with passage of time to be a function of recovery of generalization between the two stimulus situations.

V. Summary

1. Two experiments were performed to determine the influence of time and degree of prior learning on proactive inhibition, and the effect of these variables on the number of overt intrusions at recall.

2. The material used in the two lists of each experimental condition was paired two-syllable adjectives of the A–B, A–C relationship.

3. Degree of prior learning was varied in four ways in each experiment:

(a) Zero prior learning (control).
(b) First list presented until *S* anticipated three responses.
(c) First list presented until *S* anticipated eight responses.
(d) First list presented until *S* anticipated the entire list after which five additional trials were given.

4. The second list—the list to be recalled—was always presented until *S* anticipated six responses on a single trial.

5. The two experiments differed only in the length of the rest interval between learning the second list and its recall, this interval being 20 min. for one experiment and 75 min. for the other.

6. The results show that:

(a) Associative inhibition in learning the second list decreases as the degree of prior learning increases. Marked facilitation in learning the second list occurs when the prior list has been learned to a high degree.

(b) Proactive inhibition at recall increases as degree of prior learning increases.

(c) Proactive inhibition shows little change between 20 min. and 75 min.

(d) The greatest number of intrusions occur with low differentiation, i.e., with the interfering list moderately stronger than the recall list, and with the longer interval between learning and recall.

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INTENSITY OF THE CONDITIONED STIMULUS AND STRENGTH OF CONDITIONING: II. THE CONDITIONED GALVANIC SKIN RESPONSE TO AN AUDITORY STIMULUS [1]

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This experiment was designed to reveal the influence of the intensity of an auditory conditioned stimulus (CS) on strength of conditioning. The response conditioned was the palmar GSR. Electric shock was the unconditioned stimulus.

An earlier study showed that variation in the intensity of a visual CS had little effect upon the strength of conditioning of the eyelid response (4), and it seemed advisable to investigate other stimuli and responses in order to determine whether the earlier findings hold for a variety of effector systems. Since the GSR system differs widely from the eyelid effector system, and auditory stimulation is a marked departure from visual stimulation, the GSR and sound were selected as the response and the stimulus for the present experiment.

Apparatus and Procedure

1. *Apparatus.*—Experiments were conducted in a two-room sound-treated experimental suite. The *S* was blindfolded and sat alone in one room with his shock and GSR electrodes and a six-in. PM loud speaker. Polished silver electrodes were strapped to his right palm which rested on a pillow. The shock was delivered by means of electrodes fastened to his left hand. Timing, stimulating, and recording apparatus were located in the other room from which the *S* was observed by means of a one-way vision mirror.

The CS was a 200-cycle tone produced by a Jackson feedback oscillator,[3] the output of which was keyed by an automatic timing device which produced tones of one sec. duration. The keyed tone was fed to an amplifier, and thence passed through a General Radio 110 db. attenuation box to the matching transformer of the speaker. The attenuation box permitted selection of tones of intensity levels 76, 86, 96, and 106 db. above reference level as measured by a General Radio sound-level meter.

The brief electric shock was provided by the plate circuit of a '57' tube in a Muenzinger-Walz type circuit (11). The shock was adjusted until the *S* reported it to be 'unpleasant, but not painful.' On reinforcement trials it was presented at the termination of the CS.

The GSR was recorded by means of an adaptation of Greenwald's A.C. bridge circuit. This circuit was further modified along lines previously suggested (3) to increase sensitivity. Each mm. deflection of the galvanometer was the equivalent of approximately 75 ohms shift in resistance. Readings were taken directly from the galvanometer scale.

2. *The experimental design.*—The design of the experiment was essentially the same as that of the earlier eyelid response study (4). Twenty *S*s were reinforced with each intensity level, 76, 86, 96, and 106 db., of the CS. Each group of 20 *S*s was then subdivided into four groups of five *S*s each, and each of these four groups was given an extinction series with one of the four intensities of the CS, 76, 86, 97, and 106 db. Thus, each of the four intensities of CS during reinforcement was paired with each of the four intensities during extinction to give a total of 16 different groups of five *S*s each. As pointed out in the earlier paper this factorial design makes strength of conditioning orthogonal to response strength, and permits independent evaluation of the effects of generalization.

3. *Procedure.*—The general procedure was similar to that of Hovland (7). First, each *S*

[1] This research was supported in part by the Research Committee of the Graduate School of the University of Wisconsin from special funds voted by the State Legislature for 1946–47 and 1947–48. The writers wish to thank Mr. Melvin Story who helped assemble apparatus and who ran nine of the *S*s.

[2] Now with the Department of the Army, The Pentagon, Washington 25, D. C.

[3] Model 652 produced by The Jackson Electrical Instrument Co., Dayton, Ohio.

was given 10 adaptation trials with the CS intensity which was to be presented during extinction. Second, he received 20 reinforcement trials in which the *reinforced* intensity of CS and the UCS were presented together. Third, the *S* was given a 10-trial extinction series with the *extinction* intensity of the CS alone. Finally, each *S* was given a re-extinction series, consisting of five trials with the *reinforced* intensity of CS alone. The time between trials was varied unsystematically between 30 and 50 sec.

4. *Subjects.*—The 80 *Ss* were men and women students who volunteered from elementary psychology classes at the University of Wisconsin.

Results

1. *The extinction score.*—The first problem in analyzing the results was to select a suitable extinction score. A.C. responses are similar to D.C. GSRs in that they yield a markedly skewed magnitude distribution (**5, 10**), but there is less individual variation in basal level. The most simple and straight-forward extinction score would be the sum of the magnitudes of all responses during the extinction series. This magnitude score yielded a much less skewed distribution and was highly reliable. The corrected odd-even reliability coefficient was 0.92 for the 10-trial extinction series. For the five-trial re-extinction series the reliability coefficient was 0.91. The sum of the magnitudes of responses during the extinction series then was used as the *extinction score*, and the corresponding sum for the re-extinction series was used as the *re-extinction score.*

2. *Strength of conditioning.*—The basic data of the study are presented in Table I, where the mean extinction score for each of the 16 groups is given. The 16 groups are arranged in a four-row four-column square according to the four reinforcement intensities (rows) and four extinction intensities (columns). The influence of CS intensity on strength of conditioning is reflected by variation in the row means. The row means are presented graphically in Fig. 1. They lie on the curve labelled 'Strength of Conditioning.' The experimental design makes this variation independent of the direct effect of the intensity of the extinction CS upon response strength.

Examination of the row means of Table I fails to reveal any progressive increase in strength of conditioning with increasing intensity of CS. The apparent absence of trend is borne out by the analysis of variance of the data of Table I. There are three degrees of freedom for the rows of Table I, three for the columns, nine for interaction, and 64 degrees of freedom for the error estimate. The *F* for row variation was 1.53, which was not significant. (The error mean-square was 264.17.) Thus, CS intensity cannot be said to affect strength of conditioning.

TABLE I

GSR Magnitude Scores During Extinction, Averaged for Each Group with Row and Column Means

		CS Intensity (db) during Extinction				Row Means
		76	*86*	*96*	*106*	
CS Intensity (db) during Reinforcement	*106*	199.2	77.6	155.8	230.8	165.8
	96	119.8	297.4	258.6	427.4	275.8
	86	119.0	155.6	331.4	270.8	219.2
	76	265.14	213.0	180.2	244.2	225.7
Column Means		175.8	185.9	231.5	293.3	221.64 (General Mean)

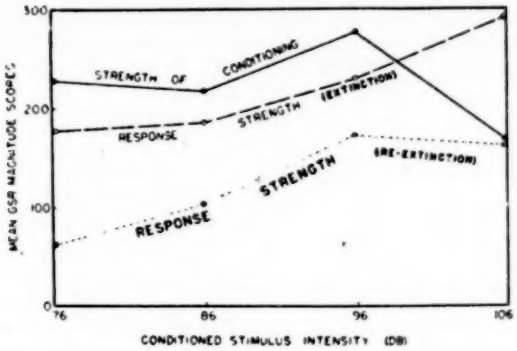

FIG. 1. Strength of conditioning and response strength measures as a function of the intensity of the conditioned stimulus

3. *Generalization effects.*—The data of Table I permit derivation of an intensive generalization gradient of excitation by averaging the diagonal cell entries according to whether the *S* was extinguished with: (a) the same CS as that used during reinforcement; (b) a CS 10 db. removed; (c) a CS 20 db. removed; or (d) a CS 30 db. removed from the reinforced CS. The respective means for 0, 10, 20, and 30 db. removed were 227, 257, 162, and 222. These means appear to follow no particular trend; and, consequently, the excitatory generalization effects were not sufficient to produce significant interaction in the analysis of variance.[4]

The presence of generalization of extinction could be tested by analyzing the re-extinction scores. Presumably, initial extinction of a response to a stimulus which differs from the re-extinction stimulus by 10 db. would have a greater depressing effect on re-extinction than would initial extinction to a stimulus 20 or 30 db. removed from the re-extinction stimulus. The re-extinction data are presented in Table II in the same general way that the extinction data were presented in Table I. The generalization gradient for extinction effects is irregular and shows very little trend as was the case with the excitatory curve. This apparent absence of diagonal variation is further confirmed by the failure of the interaction mean-square computed from Table II to attain significance.

No significant generalization effects, excitatory or inhibitory, appeared in the present data.

4. *Response strength.*—The direct effects of the intensity of the CS upon *response strength* has been distinguished from the effects on *strength of conditioning* (6, p. 142). Earlier experiments have resulted in response strength trends (see 6 for summary), but in no instance have satisfactory fiducial grounds been given for these trends. The present study provided two opportunities to test this effect, first, during extinction, and second, during re-extinction. In the first instance, effects of CS intensity upon response strength would appear as increases in column means of Table I with increased CS intensity. These

[4] Significant variation between diagonal cells of Table I (or III) would presumably denote significant generalization effects and would result in significant *F*'s for interaction in the analysis of variance.

TABLE II

GSR Magnitude Scores during Re-extinction, Averaged for Each Group with Row and Column Means

		CS Intensity (db) during Extinction				Row Means
		76	*86*	*96*	*106*	
CS Intensity (db) during Re-extinction	*106*	296.8	120.8	124.6	125.0	166.8
	96	163.6	277.0	120.4	127.8	172.2
	86	75.0	93.8	152.0	89.4	102.6
	76	131.6	58.2	13.2	66.8	67.4
Column Means		166.8	137.4	102.6	102.2	127.25 (General Mean)

column means lie on the curve marked 'Response Strength (Extinction)' in Fig. 1. This increment did occur, but the column variation fell just short of the five percent level of significance ($F = 2.17$). The re-extinction data, however, also show a response strength effect in the row means of Table II. The row means of Table II lie on the curve labelled 'Response Strength (Re-extinction)' in Fig. 1. The row means increase with successive increments in CS intensity; and furthermore, the F of 4.24 for variation in row means was clearly significant at the one percent confidence level (13, p. 225). (The error variance was 121.75.) Thus the data of Table II provide fairly conclusive evidence that response strength of the conditioned GSR is affected by the intensity of the CS. This result, of course, is quite in line with previous data on the unconditioned GSR (17).

Discussion

The essential finding of this investigation was the absence of a statistically demonstrable effect of a wide range of CS intensity upon the strength of conditioning. The lack of statistical significance in spite of the use of highly reliable measures and a powerful statistical test (2) corroborates and generalizes the findings of the previous experiment on the conditioned eyelid response to light.

The interpretation to be placed on the results has been outlined (4). If the intensity of the CS has no effect upon strength of conditioning—assuming the intensity is clearly supraliminal—arguments in terms of the magnitude of the stimulus trace can scarcely be invoked to explain such phenomena as optimal temporal intervals between CS and UCS (8, Ch. XI). The role of the CS apparently is reduced to that of a signal which triggers the conditioning mechanism. The delicate time relations in conditioning (15, 16, 1, 12, 9, 14) must then be interpreted in terms of more obscure properties of the various neuromuscular systems involved. As an example, the argument associated with optimal values of the stimulus trace will apply equally well to an interpretation in terms of definite periodic phenomena or resonance in the action systems involved in conditioning.

Summary

Strength of conditioning of the GSR was investigated as a function of the intensity of a conditioned auditory stimulus. Effects of intensity of the CS upon strength of conditioning were

separated from effects upon simple response strength by means of a factorial experimental design. Sixteen experimental groups of five *Ss* each were used. In the 16 groups all combinations of four intensities of CS during reinforcement were paired with the same four intensities during extinction. The four conditioned stimuli were 200 cycle tones of 76, 86, 96, and 106 db. intensity levels. Each *S* received a 10-trial adaptation series with the *extinction* intensity of the CS alone, a 20-trial reinforcement series with the *reinforcement* intensity of the CS and an electric shock as UCS, a 10-trial extinction series with the *extinction* intensity of the CS, and finally a 5-trial re-extinction series with the *reinforcement* intensity of the CS. The magnitude of GSR's during extinction and also during re-extinction were tested by means of analysis of variance. The principal findings were as follows:

1. There were no statistically significant effects of CS intensity upon strength of conditioning in spite of the high reliability of the conditioning scores and the considerable power of the statistical tests used.

2. The generalization trends were roughly in the expected directions, but neither excitatory nor inhibitory generalization was statistically significant.

3. Response strength increased with increasing CS intensity for both the extinction and re-extinction data, and in the latter case the trend was statistically significant.

4. It was pointed out that the findings corroborate and extend the similar results obtained with the conditioned eyelid response to light. The advisability of rejecting certain aspects of stimulus trace theory was pointed out, and it was suggested that previous stimulus trace arguments could be applied equally well in terms of other mechanisms such as resonance characteristics of neuro-muscular systems.

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RELATIONSHIP BETWEEN REMINISCENCE AND TYPE OF LEARNING TECHNIQUE IN SERIAL ANTICIPATION LEARNING[1]

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This is the first of a series of reports concerning the methodology of studies of reminiscence in verbal learning. As pointed out by one of the authors in an earlier review of reminiscence literature (1), certain of the disagreements among investigators may turn out, as is often the case, to be based on differences in experimental procedure. The present experiment is concerned with the question: what is the effect (upon the measured amount of reminiscence) of requiring *S* to pronounce, rather than to spell, the syllables learned by a serial anticipation method? It will be seen, in a later section of this report, that this seemingly minor study of technique has certain theoretical implications also.

PROCEDURE

Lists.—Syllables were presented on a modified Hull-type drum at a 2 sec. rate. There was a 'ready' symbol two sec. before the first syllable, and there were four sec. between the last syllable and the cue symbol. Eight tapes were prepared —four for the practice week and four for the experimental week. Each list contained 12 syllables, typed in bulletin size type. All syllables were taken from materials assembled by Melton (5), were of low association value, and were formed into lists according to the usual rules for list-construction.

Rest interval activity.—At the side of each tape 15 color patches were so placed that one was visible at each position of the drum when desired. Simply by opening the drum aperture before the colors, and closing that before the syllables, *S* could be shifted from syllable learning to color naming. The same color sequence was employed for each tape. (Easily named colors were cut from construction paper and stapled on the tapes; for the names of these colors and for the actual syllables employed, see Ross, 7.)

Subjects.—A total of 32 college students were used—24 women and 8 men. They were all volunteers from an elementary psychology class, and were not experienced *S*s.

Experimental design.—During the experimental week there were four sessions for each *S*: pronunciation-control (P), pronunciation-rest (PR), spelling-control (S), and spelling-rest (SR). In the control conditions *S* learned to 12/12 correct without special rest, while in the rest conditions he named colors for two min. following the attainment of a 7/12 criterion, and then learned without further special rest to 12/12. (During the practice week, such a rest was introduced somewhere after the 7/12 criterion was reached, except on one day when it was delayed until after 12/12. To give *S* additional practice in the shift to and from color-naming, two min. of color naming and two min. of syllable anticipation were added when he reached the 12/12 criterion each day except the one referred to in the preceding sentence.)

The experimental sessions were counterbalanced so that two spelling or pronunciation conditions never occurred consecutively. It was also arranged that no *S* followed the same order in the experimental week as in the practice week. Since a separate list was used for each day, the counterbalancing could be arranged so that the four experimental conditions were represented the same number of times on each list and day.

At the first practice session *S* read a printed page of instructions silently while *E* read them aloud (for details, see Ross, 7). These instructions differed from the usual ones only in that they prepared *S* to spell or pronounce, depending on the initial instruction each day. The list

[1] The substance of this report was presented at a session of Section I, AAAS, Dec. 29, 1947, Chicago. It is based on a thesis by Ross (7) at the State University of Iowa, the data being recomputed in their present form, and this report prepared, by the first author.

was then presented under whatever conditions were to be used at this first sitting. If a rest condition, the drum was stopped at attainment of the 7/12 criterion, and instructions given concerning color naming. After color naming the drum was again stopped and instructions given for the shift back to syllable learning. After the second practice day the remarks 'Now colors' and 'Back to the list' sufficed to control these shifts.

It was discovered by means of a questionnaire at the end of the experiment that color naming during rest did not completely eliminate rehearsal. Rehearsing or thinking of lists during color naming was reported by 13 *Ss* as occurring once in a while, by 15 as occurring quite often, and by 4 as occurring frequently. But the evidence did not indicate that rehearsal, whether effective or not, occurred more commonly with the spelling technique than with pronunciation.

Results

General practice effects.—Since on every day of the experiment, *S* learned to a 7/12 criterion (either before rest was introduced, or on the way to the first perfect trial), it is possible to determine the mean number of trials to this criterion day by day. On the four experimental days these means (and their *SD*'s) were, in order: 10.97 (5.58), 10.16 (5.13), 9.59 (3.22), 11.00 (4.63). Thus, the practice curve was approximately level during collection of the experimental data, and general practice effects presumably are not a differential in the results.

Recall data.—It is assumed here, as previously (1, p. 314), that recall data, i.e., scores on the first trial after reaching 7/12 correct, are the most pertinent indicators of reminiscence. Our main analysis of results therefore concerns recall data only.

Shown in Table I are mean scores at the criterion trial and mean scores on the recall trial, for each of the four conditions. It is apparent that initial level of mastery (score on the criterion trial) is almost exactly the same in all conditions except that of spelling-rest, and this departure is reasonably small.

TABLE I

Unadjusted Means for Criterion and Recall Scores, and Their *SD*'s ($N = 32$)

	Pronounce		Spell	
	Rest	No-Rest	Rest	No-Rest
M (cri.)	7.47	7.44	7.31	7.47
SD	.69	.52	.49	.64
M (rec.)	7.59	6.50	6.94	6.63
SD	1.39	1.80	1.70	1.55

The design of the experiment was such that analysis of co-variance could be employed profitably in the evaluation of these results, and a technique described by Snedecor (8, p. 333) was applied. With this technique it is possible to use an estimate of error from which has been removed the variance due to using the same *Ss* in all conditions of the experiment, as well as other experimentally defined variances. Table II shows the relevant data.

TABLE II

Analysis of Co-variance, Recall Data

Source of Variance	*d.f.*	*F*	*P*
1. Resid. (error)	92		
2. Pro.-spell.	1	<1.00	
3. Rest-no-rest	1	6.94	.01
4. Interaction	1	1.93	

(1) In using this type of analysis, it is to be expected that recall scores for pronunciation and for spelling should not differ, for both rest and no-rest conditions are included within each category. The *F*-value for this variance (line 2) is, indeed, less than 1.00. (2) The variance due to introduction of rest might be expected to be significant, even though it includes both pronunciation and spelling within each category. The *F*-value for the rest-no-rest variable (line 3) is almost

exactly that required at the .01 level of confidence. Since the rest-no-rest variance is significant it is meaningful to test, by conventional *t*'s, the difference between rest and no-rest recall means, for pronunciation and spelling conditions separately. As shown in Table III, the introduction of rest when pronunciation is used leads to a superiority of recall which is significant at nearly the .01 level, while introduction of rest with the spelling technique leads to an unreliable amount of advantage at recall. (3) To refer again to Table II, the most critical test for purposes of this investigation is the one for interaction between learning technique and the rest variable (line 4). The *F*-value for this interaction is well below that required at the .05 level of confidence.

TABLE III

SIGNIFICANCE TESTS FOR DIFFERENCES BETWEEN ADJUSTED RECALL MEANS

	Rest	No-Rest	$\sigma_{diff.}$*	*d.f.*	*t***
Pro.	7.54	6.49	.41	91	2.56
Spell.	7.05	6.58	.41	91	1.15

* Based on error mean squares of Table II.
** $P = .01 = 2.63$.

To interpret these data, the interpolation of rest leads to a reliable gain where pronunciation is being employed, to an unreliable gain where spelling is used, and the difference between an unreliable and a reliable gain is itself unreliable. It must be inferred, therefore, that the technique of learning (spelling vs. pronunciation) is of only minor significance in, for example, the failure of Melton and Stone (6) to find reminiscence when they employed a pronunciation technique, as compared to Ward's (9) success in finding reminiscence when he used a spelling technique. Indeed, in these two studies the findings were exactly the opposite of what the present data would lead one to predict from knowledge about the learning techniques employed.

TABLE IV

UNADJUSTED MEANS FOR TRIALS TO LEARN TO 7/12 AND TO RELEARN TO 12/12, AND THEIR *SD*'s ($N = 32$)

	Pronounce		Spell	
	Rest	No-Rest	Rest	No-Rest
Learn	9.59	9.00	11.66	11.56
SD	3.26	4.23	4.65	6.11
Relearn	8.69	9.72	12.66	12.38
SD	5.42	3.87	9.46	6.98

Re-learning data.—Table IV shows the mean numbers of trials required to reach the criterion of 7/12, for all conditions, and the mean number of trials to re-learn and go the 12/12 criterion. Within spelling, and within pronunciation, the rest and no-rest conditions are only moderately well-equated. But it is more difficult to learn by the spelling technique (i.e., more trials are required to reach a common criterion): analysis of variance in this table (using an error term based on the residual variance referred to in Table V) results in an *F*-ratio of 13.02 (.01 level = 6.93), indicating that spelling is reliably more difficult than pronunciation.

The effects of the single interpolated rest may again be evaluated by analysis of co-variance (Table V). (1) This table shows (line 2) that the differential difficulty of the pronuncia-

TABLE V

ANALYSIS OF CO-VARIANCE, RELEARNING DATA

Source of Variance	*d.f.*	*F*	*P*
1. Resid. (error)	92		
2. Pro.-spell.	1	13.00	.01
3. Rest-no-rest	1	<1.00	
4. Interaction	1	<1.00	

tion and spelling techniques in learning to a criterion continues after rest, for the *F*-value for this variable is significant well beyond the .01 level of confidence. (2) The introduction of the single rest has negligible influence upon re-learning, as shown by the fact that the rest-no-rest variance (line 3) is smaller than the error variance. (3) Likewise, the interaction between learning technique and the rest variable (line 4) has a variance smaller than the error variance.

Results Bearing on Theory of Reminiscence

In the monograph of Hull *et al.* (4), predictions of reminiscence are based on certain hypotheses as to how inhibition accumulates and dissipates during serial learning. It is not the purpose of the present discussion to examine very much of this theory, but simply to report on whether the indices of amount of inhibition proposed by these investigators, and the supposed relation of the indices to amount of reminiscence, are borne out by an independent study.

The Yale group suggested that, in general, the greater the amount of intra-serial inhibition generated during learning of a list, the greater would be the amount of reminiscence (as a result of dissipation of inhibition during a brief rest). Four indices of amount of inhibition were proposed: number of trials to learn; the differential in number of errors on middle syllable positions vs. end positions—i.e., degree of bowing of the serial-position curve of difficulty; amount of oscillation of response-tendencies; and reaction-latency. Reaction latencies were not recorded in the present study, but insofar as pronunciation is seemingly more conducive to the appearance of reminiscence than is spelling, it should be true that the first three indices named should be greater for pronunciation than for spelling.

(1) It has already been noted (Table IV), that number of trials to the criterion was greater for spelling than for pronunciation. According to the theory, then, there should have been more reminiscence with spelling, but the reverse was actually true. (2) As shown by analysis of co-variance, the degree of bowing of the serial position curve of difficulty is significantly greater when spelling is the technique employed ($F = 18.06$; $d.f. = 1$ and 92; .01 level = 6.93). Although, according to the theory, there thus should have been a stronger tendency toward reminiscence with spelling than with pronunciation, the reverse was true. (For purposes of these computations, numbers of trials to 7/12 in end positions were treated as the X terms, and numbers of trials to 7/12 in middle positions treated as the Y terms; in effect, the test is one for whether or not the difficulty in middle positions is greater under spelling or pronunciation, when difficulty of end positions is held constant. End positions in the 12-item list were 1–3 and 10–12 combined; middle positions were 4–9 combined.)

(3) Furthermore, the theory suggests that the amount of reminiscence in the middle of a list should be greater, relatively, than at the ends. The finding of the present study, although unreliable and therefore not presented as a definite statement, was just the reverse—with the pronunciation technique, where reminiscence occurred reliably, the gains tended to be at the ends of lists; with the spelling technique no position effects were discernible.

(4) Two measures of oscillation were calculated; they are summarized in Table VI. The first of these was the number of trials between first suc-

TABLE VI

OSCILLATION DURING LEARNING TO CRITERION OF 7/12 *

Syll. Pos.	Number of Trials Between First Success, Last Failure		Number of Reversals of Successes and Failures	
	Pron.	Spell	Pron.	Spell
1	7.13	10.06	1.13	1.66
2	9.13	12.44	1.84	2.66
3	6.75	13.44	1.56	2.81
4	7.75	12.44	1.88	2.94
5	6.69	11.28	1.66	2.91
6	4.94	9.34	1.31	2.47
7	5.03	7.25	1.47	2.03
8	4.63	6.81	1.38	2.06
9	4.81	8.25	1.44	2.56
10	4.91	7.75	1.22	2.31
11	6.19	9.47	1.44	2.41
12	5.90	10.59	1.47	2.44

* Rest and no-rest conditions combined, for each learning technique

cess and last failure for each syllable position (after Hull, 3). It will be noted that, if this serial position curve were plotted, the curve would be complex with the low points somewhere in the middle. Although this does not obscure the fact that oscillations thus defined were consistently greater for the spelling technique, it may be well to note for future purposes that this shape of curve is probably related to the fact that relatively unpracticed *Ss* were used. Such learners, not being so consistent in their performance as the better-practiced learners used, e.g., by Hovland (2), are prone to occasional failures even in end positions and near mastery of the list; since the first successes occur in end positions, the index is thereby 'inflated.' The other oscillation measure was a count of the number of times any particular syllable was given successfully one or more times, followed by one or more failures (4). This curve, if plotted, would be more similar to those usually reported for oscillations in relation to serial position. Again, however, spelling shows more oscillation than does pronunciation, and thus should have shown more reminiscence.

The net effect of this series of analyses is to indicate that, while the concept of inhibition, and its relation to reminiscence, which were developed by the Yale group were especially effective in integrating the results of their own experiments, the concepts are either not sufficiently basic ones to apply to reminiscence experiments in general, or are not as 'potent' as some unknown factor which varies as between the present study and the earlier ones. The present authors incline toward the first of these two possibilities.

SUMMARY

1. A conventional experimental design was employed for the study of reminiscence in serial learning of 12 item syllable lists. The experimental variable was introduced by requiring *Ss* either to pronounce or spell the syllables, within the several conditions of the experiment. Each of 32 *Ss* served in an experimental condition (interpolated two min. rest at 7/12 correct) and a control condition (no such rest) with each learning technique.

2. A reliable amount of reminiscence occurred with pronunciation, and an unreliable gain with spelling. Therefore, the amount of gain was not reliably greater for pronunciation than for spelling, when the two gains are compared. This particular variable in learning technique is thus probably not of major importance in explaining differences in experimental results where this factor has, among other factors, varied in the past.

3. Checks were made with respect to the indices of inhibition proposed by Hull and his co-workers, and of the expected relation of these indices to

measured amount of reminiscence. Three indices, number of trials to the criterion, degree of bowing of the serial position curve of difficulty, and number of oscillations were computed, and each indicated that there should be more reminiscence with spelling than with pronunciation. The reverse was actually true, suggesting that a revision of reminiscence theory is required.

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TRANSFER OF TRAINING FROM PRACTICE ON COMPONENTS IN A MOTOR SKILL[1]

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Introduction

The investigation reported in the present paper is concerned with the learning of a motor skill which involves the association of four simple manual reactions differing in spatial position on a reaction panel, with four different visual stimuli. This motor skill may be considered as typifying a large number of so-called complex skills which require separate reactions to be made to a number of different stimuli. The skill of typing, for example, may be considered to represent a skill of a high degree of complexity belonging to this class; many other practical situations, particularly those which require an operator to react to a panel of switches or pushbuttons, may be shown to fall within this category of skills.

The experimental problem was one of determining the extent to which transfer of training takes place to the learning of a complex motor skill, when varying amounts of initial practice have been given on a task which is itself a component activity of the total skill. Primarily, the problem was conceived in the setting of a general hypothesis with regard to the nature of the learning of activities involving a number of responses to a number of different stimuli. According to this hypothesis, such learning may be conceived as the establishment of discriminative responses to each of the stimuli presented. It is postulated that the establishment of these discriminations is accomplished by means of the mechanism of differential reinforcement, i.e., the repeated reinforcement of correct responses and non-reinforcement of wrong responses. The learning of the required discriminations is assumed to be influenced also by the degree of tendency to generalize which exists between the stimuli.

A number of deductions from a hypothesis based upon these concepts have been worked out by E. J. Gibson (13) for the learning of paired associate lists. The task utilized in the present experiment possesses many of the characteristics of such lists, except that manual, rather than verbal, reactions were required to four different panel lights. It would not be unreasonable to describe the task of the present experiment as the learning of a set of four light-manual response paired associates.

The factor in the learning situation which has particular relevance to the experiment to be reported is that of degree of learning of an initial task. The results of Hovland (17, 18) on conditioned GSR's, of Razran (22) on conditioned salivary responses, and of E. J. Gibson (14) on paired associate learning have provided measurements of the amount of generalization during the course of learning. According to these results, as the number of reinforced repetitions of the correct response is increased, generalization at first increases to a maximum and subsequently decreases. When the learning of an initial task is followed by the learning of a second task whose stimulus elements are similar, the rate of learning this second task may be expected to be

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influenced by the degree of generalization which occurs between the stimuli of the two tasks. Consequently, as the amount of practice on the initial task is increased, the difficulty of learning the second task should at first increase to a maximum and later decrease (cf. 13, p. 216).

Statement of the Problem

In general terms, the problem investigated in the present study was one of determining the way in which degree of learning of the component activities of a complex skill influences the acquisition of the total skill. We were interested, too, in discovering to what extent the integration of part activities into a total skill could be understood in terms of the generalization which is expected to occur between the components.

In the experiment to be reported, subjects were required to learn a task composed of four different motor reactions to four different stimuli. These stimuli were an upper and lower red light and an upper and lower green light on a panel. The two sets of lights were 7½ in. apart in the vertical dimension. Since these stimuli are similar to each other in many respects, it was expected that some degree of generalization would occur between the learned acts associated with them. That is to say, it was expected that in the course of training, the upper red light would acquire not only a tendency to evoke the correct response to be associated with it, but also a tendency to evoke the responses primarily associated with the upper green light, the lower red light, and the lower green light. According to the hypothesis which has been outlined, the strength of these generalized tendencies would be expected to decrease with diminishing similarity between them and the primary stimulus.

When the similarity of the various stimuli is maintained constant, as was the case in the present experiment, the amount of generalization between the competing response tendencies may be reduced by giving separate training to some of them. Such training may be considered to have the function of predifferentiation (cf. 13, p. 222). If the learning of the task which involves four differential reactions has been preceded by practice on two of these reactions, the internal generalization present in the final task should be reduced, and consequently the learning of the final task should proceed more rapidly. This effect, however, may be seen to depend in a particular manner upon the *amount* of practice devoted to predifferentiation, since the generalization which occurs during this preliminary learning is assumed to reach a peak during the early stages of practice and then to decline as learning is continued. In accordance with such a principle, a more exact prediction regarding the effect of this type of predifferentiation may be stated as follows: If the amount of practice on an initial task involving predifferentiation is increased, the learning of the final task will at first be slowed because of an increase of internal generalization. Following this, the learning of the second task will be made more rapid as the amount of generalization produced by the initial practice passes through a maximum and decreases.

In the experiment to be reported, three different amounts of preliminary training on two of the component reactions, namely 10, 30, and 50 trials, were given. Each of these was followed by 60 trials of learning on the total skill. An additional group, the control, received no preliminary training on component reactions. It is reasoned that the change in degree of generalization related to the differential training should be measurable

during the course of the learning of the total skill which follows the preliminary training, and should reveal itself as a difference in rate of learning and in number of errors. The number of errors which occur during the final learning is assumed to be a measure of the generalization tendencies rather than a measure of the progress of learning, which is provided in our experiment by the time for each reaction. The error score obtained during the course of this final learning may therefore be expected to exhibit changes which correspond to the changes in generalization during learning. The prediction may be made that the total number of errors exhibited during the final learning will be high in groups having no predifferentiating learning, even higher in a group having only a slight amount of such preliminary training, and then progressively lower in groups having an amount of preliminary training on component reactions sufficient to bring about a reduction in generalization tendencies.

If the effect of different amounts of preliminary training is to change the total amount of generalization occurring during the final learning, it is conceivable that varying rates of progress might appear *within* the 60 trials devoted to the learning of the total skill. Considerable slowing down of of the rate might result in a flat portion of the final learning curve which could be called a plateau. Such plateaus, if they do occur, may be expected to be dependent upon the degree of generalization which occurs, and consequently on the degree of predifferentiating learning which has been given. This line of reasoning recalls the classic investigation of plateaus by Bryan and Harter (**7, 8**), which suggests that plateaus occur when the subordinate skills have been insufficiently 'consolidated' to permit the integration of the total skill. We believe our hypothesis to be not essentially different from this, except insofar as it would substitute 'differentiation' for 'consolidation.' Thus, it is proposed that the learning of a total skill of the sort studied may be slowed at particular stages during the course of learning because of the tendency of the component reactions to generalize with each other.

A word should be said concerning the relation of verbal responses to the performance of this skill. It would be fruitless to deny that when a motor skill such as the one considered in this investigation is learned, the subject engages in a good deal of implicit verbal behavior during the course of learning. There is no question that the kind and amount of these verbal responses exert a considerable influence on the learning of the skill, as many studies on the transfer of principles have demonstrated. The fact that such skills are to a considerable extent verbal in nature has sometimes been used as an argument against the possibility of applying the concepts of conditioned response learning to the learning of motor tasks in human beings.

It will be noted that no attempt was made in our experiment to measure the effects of such verbal conceptualizations of the problem on the course of learning. On the contrary, instructions given to the subject at the beginning of the learning included and emphasized a verbal conceptualization of the task. It was expected that the subject would learn the skill, in part at least, by acquiring a principle in verbal terms such as 'Red-One, Green-Two; Lower-Left, Upper-Right.' It is not our intention to deny that such verbalization occurred or to underestimate its importance. Instead, the attempt was made to keep the nature of this verbal principle as constant as possible for all subjects by stating it specifically in the instructions. What we are assuming is that the learning of such a skill, including this verbal conceptualization of the problem, rests fun-

damentally upon the principles of differential reinforcement and generalization as they are exhibited in the learning of animals which do not possess the capacity for making this type of verbal reaction. A similar point of view may be found in studies which use these concepts to account for the learning of overt verbal responses, including meaningful words, in human beings.

Relation to Other Studies

Studies of transfer.—A number of experiments on transfer of training have provided evidence concerning the relation between amount of preliminary practice and degree of transfer to a final task. In a study of transfer between the learning of nonsense syllable paired associates, Bruce (6) found a number of conditions of similarity of the first and second tasks in which a maximum amount of negative transfer resulted following two repetitions of the first list. Measurement of transfer after six and after 12 trials of practice on the first list showed a reduction in the amount of negative transfer and in many instances the appearance of positive transfer. The results of Siipola and Israel (23) show an increase in interference with a partly learned final task in a group having a small amount of training on an initial task. The tasks used in this experiment were two forms of code learning. With increasing mastery of the initial task, the data indicate increasing degrees of positive transfer. A similar finding was obtained by Wiltbank (26) on transfer from one maze to another. His results show a slight degree of interference following 2, 4, and 8 trials of initial training, and the appearance of positive transfer after 16 trials of such training.

It is evident from Bruce's (6) results that the occurrence and the amount of inversion from negative to positive transfer following varying degrees of initial training is dependent upon the degrees of similarity of the stimulus and response members of the two tasks. Possibly because of differences in this factor, some studies show only an increasing amount of positive transfer with increased practice on the initial task. This was the finding in Ho's study (16) of transfer between two relatively similar mazes. In this experiment, rats received 0, 3, 15, or 71 trials on one maze before learning a second. The three transfer groups all show positive transfer from the first to the second maze, and the amount of transfer increases as the amount of preliminary training increases. In an experiment by Bair (1), subjects dealt cards 1, 20, 30, or 40 times before dealing to a changed position with the cards arranged in a different order. The results indicated that the greater the degree of practice in one order, the shorter is the time to complete the dealing in a different order. The study of Bray (4), which was concerned with the measurement of transfer from practice in the activity of hitting a target with the right hand to the same activity performed with the right foot, indicates that in such a task the increased positive transfer following increasing amounts of practice on an initial task soon reaches a limit. Subjects were given practice of from 10 to 60 trials in hitting a target with the right hand. No difference in amount of transfer to right foot performance was found after these different amounts of practice.

Several experiments have investigated the relationship between the amount of transfer and the stage of learning of the final task at which such transfer is measured. The usual finding is that as the learning of the task proceeds, the amount of final transfer that can be measured undergoes a decrease. This result is more or less to be expected, since a slighter degree of improvement over and above learning is possible when the learning itself is approaching some final limit. The results of Webb (25) and of Bray (4) are illustrative of this type of finding. On the other hand, when errors are used as measures of performance as in the study of Melton and Irwin (21) with nonsense syllable lists, there is evidence of a tendency for interlist intrusion errors to increase at first and then to decrease as the learning of the final list is carried further. The relation between such re-

sults and the hypothesis which would account for such intrusion errors in terms of generalization tendencies seems evident. Also relevant are the results of Siipola and Israel (23) with code learning tasks, which indicate the occurrence of maximal interference-effects at stages of the final learning which correspond directly to the stages reached in the initial task. These results are at least partially consistent with the generalization hypothesis, since it would be predicted that increasing interference would result from partial learning of either or both the initial and final tasks. These authors, however, interpret the interference as resulting from the conflict of sets involved in the two tasks.

Studies of plateaus.—Since the experiment to be reported in the present paper deals with some relationships between training on a total skill and training on component reactions of this skill, it has a derivative relation to the investigation of Bryan and Harter (7, 8), and particularly to the hypothesis that plateaus in the curve of skill acquisition result from the interaction of lower and higher order habits. These investigators suggested that plateaus occurred in the course of learning a total skill when one or more of the subordinate skills was insufficiently 'consolidated,' or perfected, to permit the further integration of the total skill. Book (3) also presents evidence to support this view. It may readily be seen that the same line of reasoning would lead to the conclusion that if the subordinate skills in question were to be practiced sufficiently before training was begun on the total skill, the plateaus would not appear. The experiment to be described provides some evidence on this point, since it involves the measurement of acquisition of a total motor skill following varying amounts of practice on subordinate skills.

The studies of Batson (2), Smith (24), and Kao (19) are also concerned with the integration of components in complex motor skills. The task in Smith's study was one of tossing a ball alternately with the left and right hands to hit left and right hand targets on a wall with a force which would make the ball bounce to a target on the floor. The subjects in this experiment practiced various components of the total task before attempting to perform the whole activity. The components were fairly similar to each other, and some evidence of interference was obtained when two or more of them were put together. Interference usually occurred at the stage when new, unpracticed components were added to the task to be performed alternately or successively with old and more practiced components. Kao, in one experiment, used a total task which required the subject to hit a swinging pendulum. The subjects practiced separately the components of aiming in a particular direction, at a particular time, and with a given force before attempting to learn the total skill which involved the integration of all three components. In another experiment, this author studied the acquisition of the skill of throwing, into a target, shot picked up from a board with tongs. Again the subjects practiced the components of this skill separately and later attempted to perform the total skill. In general, Kao's results indicate that plateaus occur in the case of these skills only when the subjects attend to the part processes separately. Undoubtedly, these results may be interpreted to mean that not all complex skills are subject to the occurrence of plateaus during the course of their acquisition. The results of our experiment support the point of view that the occurrence of plateaus is a matter which depends, under specific conditions of similarity, upon the degree of training of the component activities which make up a skill.

Method

In general outline, the procedure followed in the present investigation was to give different amounts of training to separate groups of subjects on an initial task which was a subordinate part of a total skill involving four differential manual reactions. Following the initial training, each group

learned the total skill to a high degree of proficiency, and this learning was measured throughout its course.

Subjects.—The subjects used in the experiment were 170 young Navy enlisted men of age range 18–28, who were taking the physical examination for entry into Submarine School. These men formed a relatively homogeneous sample, since they had been selected on the basis of a number of qualifications, including those of having volunteered for submarine duty, of being above average in intelligence as measured by Navy tests, of meeting certain minimum physical requirements, and of displaying no evidence of emotional instability. They were selected at random for use as subjects in the experiment, and no factors are known which could have operated to produce differential selection in the different experimental groups. The men were divided into five groups of approximately equal size, each group being employed in one of the five experimental conditions. After matching, the data obtained from thirty men in each group were used.

The groups were matched on the basis of two criteria: (1) a learning score obtained from the administration of the full-page Woodworth-Wells digit-symbol test with a time limit of 90 sec.; and (2) a measure of reaction time obtained in 25 trials of reaction to a single green light of the apparatus by pressing a single switch. The latter measurement was obtained in each subject at the end of the experimental session. The subject was instructed to react only to the lower green light, not to the upper green light, which was occasionally presented. The values obtained consequently represented 'discrimination' reaction time. The learning score of each individual was first matched with a score in each of the other groups. Following this, reaction time scores were matched individually in all the groups. The means and standard deviations of these scores in the groups as finally matched are shown in Table I.

It may be seen from Table I that the groups were fairly successfully matched on the basis of these two criteria. The multiple correlation between these two measures and total time of all learning trials in the control group was .424. Another measure of the matching is provided by a comparison of initial learning scores, in terms of the average time on the first 10 trials of the initial task, between all groups except the control. The means and standard deviations of these scores are shown in the two final rows of Table I. These values also indicate fairly close agreement, so that the differences found in the experiment cannot reasonably be attributed in any large part to differences in the character of the groups themselves.

Apparatus.—The subject's part of the apparatus is shown in Fig. 1. It consists of a display panel containing two sets of red and green lights, one set 7½ in. above the other; and a reaction panel containing a starting button in front, on which the subject's thumb rests before each reaction, and four bat-handle spring-return toggle switches, two on the left and two on the right of the center. The two switches on both the left and the right are numbered 1 and 2 respectively, beginning from the left.

In operation, the experimenter turns on any one of the four lights by depressing an appropriate button on his control panel. At the same time, an electric timer is started automatically by the apparatus. The subject responds by pressing momentarily the correct switch as defined to him by the instructions. The pressing of the proper switch turns out the light and stops the timer. If an incorrect switch is pressed, the light continues to glow and the timer to run,

TABLE I

SCORES ON MATCHING CRITERIA

Measure	Group '0'	Group '10'	Group '30'	Group '50'	Group '30B'
Substitution Test—number right					
Mean	66.0	65.6	66.9	66.2	67.0
SD	11.5	10.9	11.2	11.4	11.8
Reaction Time—sec.					
Mean	.373	.393	.371	.384	.400
SD	.051	.063	.067	.058	.057
Initial Task (10 trials)—1/100 sec.					
Mean		59.8	60.9	54.7	57.1
SD		8.4	10.3	7.3	9.3

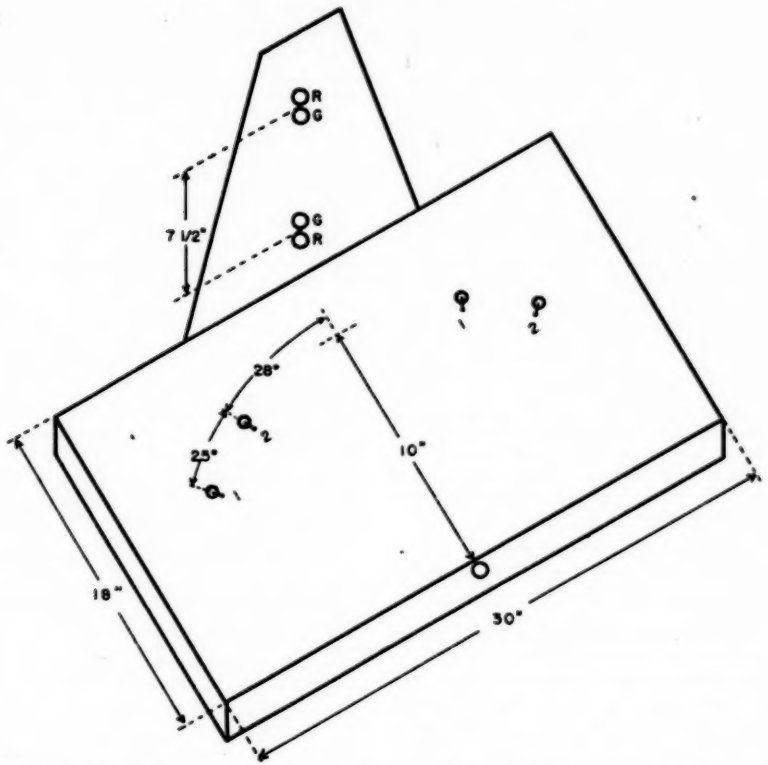

FIG. 1. Schematic diagram of the subject's panel. R, red light; G, green light; 1, 2, switches

until the subject makes a correct reaction. When the timer has been read and reset by the experimenter, the apparatus is ready for the next presentation of one of the four lights.

Instructions.—The instructions given to the subject at the beginning of practice on the initial (subordinate skill) task were as follows. During this time, two of the switches were covered with rounded wooden covers which did not interfere with the subject's movements toward the other two switches.

> This apparatus measures your reaction time. Using your preferred hand, always start with your thumb resting on this button. (Demonstrate.) First we will work with only two lights and two switches. If a *lower* (green) (red) light goes on, you should react by pressing the switch on the *left*, as quickly as you can. (Demonstrate.) If the *upper* (green) (red) light goes on, press the switch on the *right* as quickly as you can. Return your hand to the starting button after each reaction.
>
> Now we shall run through a number of these reactions. Try to make as fast a reaction as you can, without moving in the wrong direction. Your score on each trial can be seen on this clock, which reads in hundredths of a second. I shall read off your score each time, so that you can keep track of your own improvement. All ready to begin? Remember, if the lower light goes on, press the switch on the left; the upper light, the switch on the right. Ready.

After the given number of trials had been run on the initial task, the experimenter removed the wooden covers from the switches and gave the following instructions:

> Now we'll try it with four lights and four switches. Just as before, a *lower* light means a reaction to the *left*, an *upper* light a reaction

to the *right*. A *red* light means switch number *one* (point), a *green* light, switch number *two* (point). Thus, if the lower red light goes on, react by pressing switch number *one* on the *left*;—the lower green light, switch number *two* on the *left*. When the upper red light goes on, react by pressing switch number one on the right; the upper green light, switch number two on the right. Return your hand to the starting button after each reaction. If you press the wrong switch, the light will not go off and the clock will continue to go around. So you should then press the correct switch as quickly as you can. The lights are presented in random order, so you will only slow yourself up if you try to figure out which one comes next. The clock will record your reaction time, as before, and I shall read it off to you so that you can keep track of your improvement.

Now we are ready to begin. Remember, a lower light means a reaction to the left, an upper one to the right. Read means switch number one and green, switch number two. All set? (If necessary, part of the instructions may be repeated here.) Ready.

The latter set of instructions was slightly modified in its beginning portion for use with the control group, which had no training on the initial task.

Procedure.—At the beginning of each experimental session, the full-page Woodworth-Wells digit-symbol test was administered to the subject with a time limit of 90 sec. Following this, the subject was seated comfortably in a chair facing the apparatus, and was given 10, 30, or 50 trials on the initial task, which required the learning of only a right-left discrimination, but not a red-green discrimination. (The control group was not given this training.) Half the subjects in each group were trained on this task with the use of only the red lights, half with only the green lights. During this training, the two switches not in use were covered up with small rounded wooden covers. After the training on the initial task was completed, all four switches were exposed, and the subject practiced the final task during 60 trials. In the case of the control group, 80 trials were given on this task in order to reach a more final stage of learning. Four different predetermined random orders of stimulus presentation were used for an approximately equal proportion of subjects in each group. After a correct response was made by the subject, the experimenter read aloud and recorded the reading of the timer in hundredths of a sec. The number of incorrect switches (if any) pressed by the subject during the trial was also recorded. That is, if a subject pressed one wrong switch before pressing the correct one, an error score of 1 was recorded; if he pressed two wrong switches before the correct one, an error score of 2 was recorded, etc. The time score on a trial in which errors occurred was naturally a good deal higher than the score on the usual errorless trial.

Group 30B was treated in the same way as the other groups, except that 30 trials were given on an initial task which involved learning differential reactions to the red and green lights. Half of the subjects in this group used switches 1 and 2 on the left for this initial training, and half used switches 1 and 2 on the right. These subjects were then given 60 trials of training on the final task involving all four switches.

The time interval between trials was maintained at the approximately constant value of 10 sec. during both the preliminary and final training in all groups. The time elapsing between the end of the initial task and the beginning of practice on the final task was 2–3 min.

Upon the completion of training in the final task, the reaction time of each subject, in all groups, was measured in 25 trials of reaction to switch 2 on the left, on the appearance of the lower green light. This measure was taken for use in the matching of groups.

Treatment of data.—The experiment yielded a time score and an error score for each subject on each of 60 trials of practice on the final four-position skill. For the control group, these measures were obtained in 80 trials. The performance was measured by averaging the time values for each successive set of 10 trials of learning of the final complex task after 0, 10, 30, and 50 trials of practice on the right-left discrimination, and after 30 trials of practice on the switch 1-switch 2 discrimination. The significance of the differences in these scores between the groups was tested at the beginning, in the middle, and at the end of the final learning. The amount of transfer found after each amount of preliminary training was expressed as the percent that improvement due to transfer was of the total improvement possible.

Results

Learning.—The final-task learning scores of each of the five groups employed in the experiment are given in Table II in terms of average time per trial throughout successive sets of ten trials. For the control group, these scores extend through 80 trials; for the other groups, through 60 trials. Standard deviations of these average time scores are also given, computed with an N equal to 300, the number

TABLE II

TIME OF RESPONSE PER TRIAL (IN 1/100 SEC.) IN SUCCESSIVE 10-TRIAL STAGES OF LEARNING THE TOTAL SKILL. $N = 300$

Group	Trials							
	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
0-Trial								
Mean	108.0	95.7	95.4	92.0	82.3	78.2	78.0	79.9
SD	67.2	51.7	54.0	54.2	45.0	43.6	37.2	45.5
10-Trial								
Mean	109.9	97.2	97.0	87.9	85.1	82.5		
SD	76.6	56.4	63.7	48.8	48.9	50.6		
30-Trial								
Mean	97.4	94.1	83.3	83.3	78.0	75.3		
SD	66.3	63.3	49.4	55.7	36.9	44.7		
30-Trial (B)								
Mean	100.9	89.1	90.6	84.7	81.3	81.3		
SD	68.9	53.5	57.7	46.2	43.2	46.8		
50-Trial								
Mean	88.9	85.2	82.9	78.6	81.4	72.8		
SD	56.1	47.5	51.5	42.8	48.4	37.1		

of individual scores included in each set. The variability of scores on individual trials is high, but the sizes of the standard deviations reflect the extended range of scores produced by the learning which went on within each set of 10 trials.

The learning of the final task in general proceeds in a negatively accelerated manner throughout its course. As measured by time scores, learning begins at very different levels in the groups having different amounts of previous training on the initial task. Differences on the first 10 final-task learning trials are considerable between the scores of the control group and the 30 and 50 trial groups. The critical ratios[2] for these differences are 2.15 and 4.17. These values indicate differences which are significant at levels of confidence of 1.6 percent and of lower than one percent, respectively. On trials 31–40, the differences between the scores of these same groups have similar degrees of significance, the critical ratios being 2.14 and 3.71. Significant differences in performance also occur between the scores of groups 10, 30, and 50 on trials 1–10, and between the scores of groups 10 and 50 on trials 31–40. By the time trials 51–60 are reached, as might be expected, the differences are no longer significant ones. In contrast to these groups, the time scores of the groups having 10 trials of preliminary training on the initial task differ significantly at no point during 60 trials on the final task from those of the control group.

Transfer.—The scores in Table II provide evidence of considerable positive transfer between 30 and 50 trials

[2] The S.E.'s of the differences were computed according to the formula $\sqrt{\frac{(1 - r^2)}{N}(\sigma_x^2 + \sigma_y^2)}$, where r is the multiple correlation between the matching criteria and a performance score of the control group obtained by finding average time of reaction in 60 trials.

of training on an initial task which represents a subordinate part of the total skill. This transfer exerts its effect, according to these results, not only during the initial stages of learning the total motor skill, but throughout 40 to 50 trials of this learning. On the other hand, when only 10 trials of preliminary training are given on the initial task, no significant evidence of transfer is obtained.

In a previous paper (12) a method of expressing transfer as a percent of total learning has been described. No exact determination was made in this experiment of the time score which represents a final steady level of performance. The final learning of the control group was carried on through 80 trials in the attempt to arrive at such a measure, but only a slight drop in the average time of reaction occurred beyond the 60th trial. It is believed that the difficulty of maintaining high motivation throughout this extended period may be responsible for the failure of these time scores to exhibit the expected drop. However, an estimation of this final level of performance may be made which is sufficiently accurate for present purposes. The measure of total (100 percent) learning which was ultimately decided upon was the lowest average time score in trials 51–60. This was the score of the group having 50 trials of training on the initial task, and had a value, in hundredths of a sec., of 72.8. It is assumed that if learning had been continued for many more trials in all the groups, the time scores would have reached a steady level at approximately this value.

The formula employed to express transfer in the present study is:

$$\text{Percent Transfer} = \frac{\text{C Group Score} - \text{T Group Score}}{\text{C Group Score} - \text{Total Possible Score}} \times 100$$

The denominator of this fraction expresses the range of scores possible in learning, whereas the numerator represents the conventional method of arriving at a value of the amount of transfer. For example, the average time score of the control group on trials 1–10 of the final task was 108.0; that of the 30 trial group on these trials was 97.4. The estimated measure of final learning, the score of the 50 trial group on trials 51–60, is 72.8. Substituting these values in the formula, we have:

$$\text{Percent transfer} = \frac{108.0 - 97.4}{108.0 - 72.8} \times 100 = 30\%$$

This value tells us simply that at the beginning of practice on the final task, 30 trials of preliminary training on the subordinate skill had already accomplished 30 percent of the total possible learning.

By applying this formula to the average time scores in Table II, we arrive at values which indicate the degree to which different amounts of practice on the subordinate skill contribute to the learning of the total motor skill throughout the course of learning this total skill. These results are shown in Fig. 2. These graphs are, of course, simply learning curves in which the raw time scores are transformed into percentage values which increase with increasing practice. They also provide a convenient method of estimating graphically the transfer effect of the preliminary training. For example, one can ask the question: By what sort of training can 60 percent learning of the total skill be accomplished? Four different combinations of preliminary and final training, according to this figure, will bring about such a result. Sixty percent learning of the total skill may be accomplished by 40 trials of practice

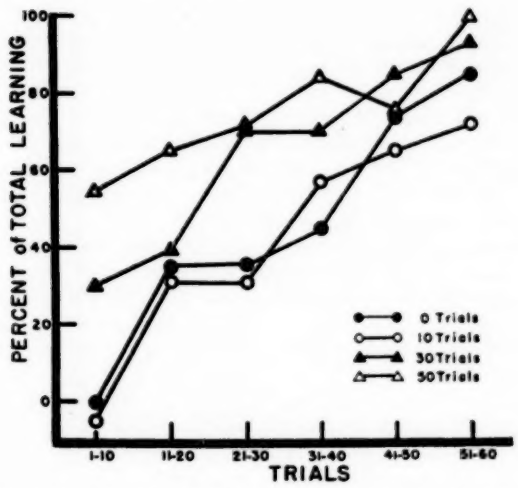

FIG. 2. Percent learning accomplished by each of four groups with different numbers of preliminary training trials at six stages of practice on the final task

on the final task; by 10 trials on the subordinate skill followed by 40 on the total skill; by 30 trials on the subordinate skill followed by 22 on the total skill; or by 50 trials on the subordinate skill followed by 10 trials on the total skill.

It is evident from these results that, in terms of number of trials to learn, the most efficient method of training for any given level of proficiency is that which begins with the total motor skill, without including preliminary practice on the subordinate skill. None of the amounts of preliminary practice given in this experiment accomplish as much learning as the same amounts of training on the total skill. However, this finding is probably less significant than the fact that a considerable degree of positive transfer does take place between practice on a part-activity and a total skill which contains this part. This result may have some degree of practical importance in planning the training of any complex motor skill in which a number of specific reactions have to be made to a number of specific stimuli. The results suggest that training on only a portion of the total number of reactions required does not necessarily interfere with training on the total skill, but in fact, may actually contribute a good deal to the attainment of proficiency in that skill.

These results serve in some measure to illuminate the problem of training by parts vs. training by wholes in a situation in which a non-serial motor task is involved. Ten trials of part-training on only two of the reactions of the four required in the total task accomplished nothing so far as the learning of the total task was concerned; 30 such trials brought the performance up to the level of 30 percent of the learning of the total task; 50 trials accomplished as much as 54 percent of the total possible learning of the whole skill. It may be expected that greater amounts of practice on the part-skill would have resulted in greater degrees of contribution to the

learning of the total skill, but to an extent which would ultimately diminish as the amount of part-skill practice was increased. Supposedly, too, there is some upper limit of contribution which training on specific components can make to the learning of the total skill, no matter how great the amount of training on these component skills. Our experiment does not provide data concerning this limit, but it does suggest that the limit of this contribution is rather high.

Another problem of interest in connection with the contribution to the total learning made by specific components is the question as to whether training on some parts of a complex skill may contribute a greater degree to the learning of the total than training on others. In the present experiment, this problem was investigated by comparing the degree of transfer to the total task resulting from preliminary training on two different kinds of component training. It will be recalled that the total task involved reacting differentially to red and green lights by pressing switch 1 and switch 2 (on both the left and the right), and reacting differentially to the up and down positions of the lights by pressing a switch on the left or a switch on the right (either switch 1 or switch 2). Group 30B was given 30 trials of preliminary training on the discrimination of reactions made to a red and a green light before being trained on the total skill. The results obtained in this group may be compared with those from the group given 30 preliminary trials on the subordinate task which involved acquiring discriminative reactions to up and down positions of the lights. The question to be answered by this comparison may be phrased in this way: Does the procedure of predifferentiating the reactions to the red-green discrimination contribute more or less to the total learning than the procedure of predifferentiating the reactions to the up-down discrimination? So far as the present motor skill is concerned, the

TABLE III

AVERAGE NUMBER OF ERRORS IN SUCCESSIVE 10-TRIAL STAGES OF LEARNING THE TOTAL SKILL. $N = 30$

Group	Trials							
	1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
0-Trial								
Mean	4.4	5.4	5.0	5.0	3.8	3.8	4.0	4.4
SD	3.0	4.0	2.3	3.6	3.2	2.7	2.7	2.6
10-Trial								
Mean	6.2	5.6	6.2	4.7	5.0	4.4		
SD	4.0	3.9	5.9	4.8	4.1	4.8		
30-Trial								
Mean	5.2	4.9	4.2	4.0	4.0	4.2		
SD	3.9	3.9	3.1	2.9	3.4	3.8		
30-Trial (B)								
Mean	5.4	4.5	4.9	3.9	3.8	3.9		
SD	3.7	2.6	3.1	2.5	2.4	2.7		
50-Trial								
Mean	3.3	4.0	3.6	3.1	3.6	2.9		
SD	2.9	3.0	2.3	2.8	2.6	2.9		

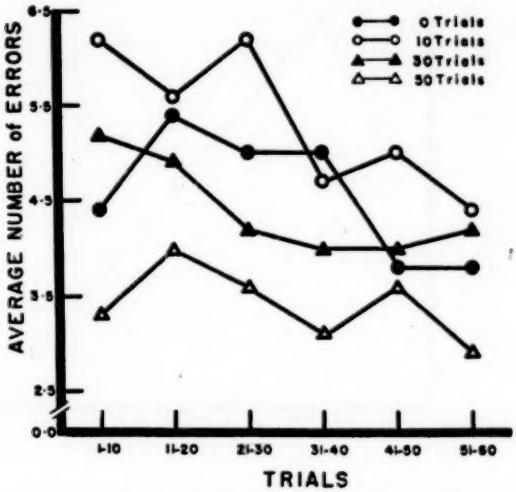

FIG. 3. Average number of errors made by each of four groups with different numbers of preliminary training trials at six stages of practice on the final task

evidence shows that the two kinds of preliminary training were equally effective. This can be seen by comparing the time scores given in Table II for groups 30 and 30B. The learning of the total task in these two groups followed an essentially similar course throughout 60 trials. No significant differences between the scores were found at any stage of the final learning. So far as this particular task is concerned, part training on one component seems to be just as effective as part training on another.

Errors.—The mean number of errors per successive sets of 10 trials of learning of the total task in each of the five groups is given in Table III, together with the standard deviation of each measure. The standard deviations give a measure of the variability of the number of errors occurring in each set of 10 trials, rather than the number occurring in each single trial. This method of comparing the variability of errors was used because the distribution of number of errors on each single trial had such restricted range. It was believed that the total number of errors during a particular period of the learning process, 10 trials, would yield a more sensitive measure of the occurrence of such errors.

It is our hypothesis, as described in a previous section, that error scores may be used as a measure of tendency to generalize. If this is true, there is little reason to expect that the frequency with which errors occur at successive stages of the learning process should exhibit resemblance to a learning curve as measured by the time score. Instead, one would expect error frequency scores to pass through a maximum at some particular stage of learning, in accordance with the results of Gibson (14). The results given in Table III do show this point of maximum generalization, as measured by errors in a number of the groups. This finding is illustrated in Fig. 3, in which the average number of errors during each set of 10 trials is

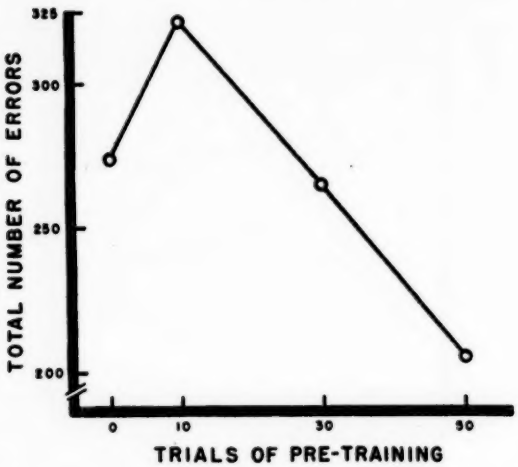

FIG. 4. Amount of generalization following different amounts of pretraining, as measured by total number of errors during 60 trials of practice on the total task

shown for the groups having 0, 10, 30, and 50 trials of training on the subordinate task.

According to our hypothesis concerning the effect of preliminary training on degree of generalization, it should be expected that, if the amount of predifferentiating training is increased, the degree of generalization should increase to a maximum and then decrease. The results shown in Fig. 3 illustrate such a trend. It will be noted that the number of errors in the group given 10 trials of preliminary training is greater than in the group which was given no such training. In the group having 30 trials of preliminary training, it may be seen that the number of errors is less than that of the control group, and in the group given 50 trials of predifferentiation, it is least.

The theoretical relationship which is indicated here may be seen more clearly in Fig. 4 in which amount of generalization during the final training, as measured by the total number of errors, is plotted as a function of amount of predifferentiating training. The resemblance between this graph and the previous finding concerning the course of generalization during learning (14, 17, 18, 22) is evident. It resembles, too, the results of Siipola and Israel (23) which indicate the occurrence of negative transfer following a small amount of training on an initial task, and the occurrence of positive transfer following greater amounts of initial training.

It may also be supposed, in accordance with our hypothesis, that the effect of increasing the number of trials of predifferentiation is to move the point of maximum generalization closer and closer to the beginning of the learning process measured in the final task. Some tendency in this direction can be seen in the error curves of Fig. 3. The point at which each error curve makes its most abrupt drop seems to occur nearer the beginning of the learning as we proceed from the 0 to the 50-trial group. Thus, so far as the final task is concerned, the point of maximum general-

ization seems to be passed in the zero-trial group at about the 40th trial; in the 10-trial group at about the 30th trial; in the 30-trial group at about the 15th trial. The group having 50 trials of preliminary training does not exhibit any marked drop in error score. A rigorous test of this prediction would undoubtedly have to be based upon measurements following a greater number of different amounts of predifferentiating training. Insofar as the data indicate these trends, however, they are consistent with the hypothesis which underlies our investigation.

Another prediction which may be made in regard to generalization involves a more intensive analysis of errors than has been presented so far. It may be supposed that different types of predifferentiating training have a differential effect upon the kind of errors which occur in the final task. It will be recalled that during the predifferentiating training on the reactions associated with up-down discrimination, half the subjects in each group were trained with the red light only, and half with the green light only. Insofar as errors during final training indicate the existence of tendency to generalize with regard to each of the stimuli employed, a greater degree of generalization to the red lights would be expected in those subjects who had been trained on the green lights, and a greater degree of generalization would be expected to the green lights in those subjects who had been trained on the red lights, provided that the preliminary training had been great enough to effect a reduction in generalization. This comparison may be made with the results obtained from Group 30. In Group 30B, in which the preliminary training involved differentiation of the red and green stimuli, a greater degree of generalization should be expected to the lights in the up-position in those subjects who were trained on the down-position, and a greater degree of generalization to the lights on the down-position should be expected in those subjects who were trained on the up-position. The results of this sort of analysis of errors are presented in Table IV, which exhibits the number of errors made during the final training to the *color of light* on which training was given in the preliminary task (in Group 30) compared with the number occurring to the color of light on which training was not given in the preliminary task. The results for

TABLE IV

COMPARISON OF TOTAL NUMBER OF ERRORS MADE DURING FINAL LEARNING TO TRAINED AND UNTRAINED STIMULI IN THE PRELIMINARY TASK

Group and Stimuli	Trials					
	1–10	11–20	21–30	31–40	41–50	51–60
Group 30						
Errors on Trained Lights	62	59	64	75	65	63
Errors on Untrained Lights	94	89	63	43	55	55
Group 30B						
Errors on Trained Position	72	58	55	52	60	62
Errors on Untrained Position	89	77	91	63	53	55
Group 0 (Control)						
Errors/2	66	80	74	76	58	57

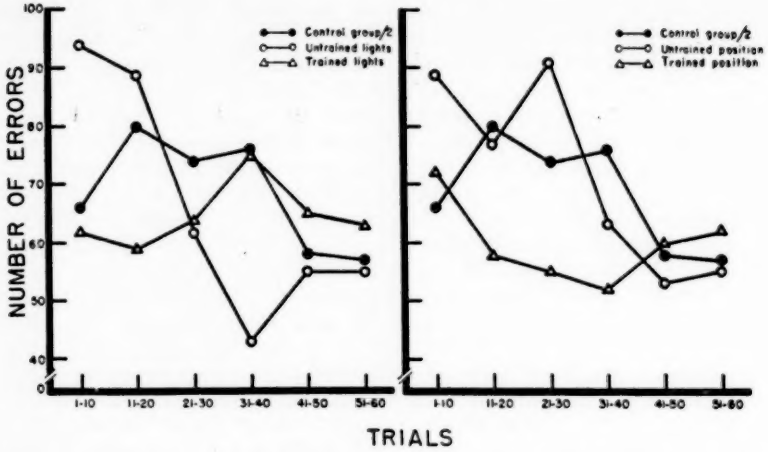

FIG. 5. Number of errors made in final learning to stimuli used and to stimuli not used in 30 trials of preliminary training, compared with errors made by the control group to the same number of stimuli

Group 30B in this table show the number of errors occurring in the final task to the *position* on which training was given in the preliminary task, as compared with the number of errors to the position on which training was not given.

The differences in the total number and the course of these errors during the final learning are striking, and are quite similar in both groups. The results may be seen graphically in Fig. 5. This figure shows that in the case of both of these groups trained on different components of the task, the degree of generalization to the lights (or positions) on which preliminary training was given was considerably reduced below the level of generalization to the stimuli measured in the control group. The graph of errors for the control group in this figure has been made by dividing the total number of errors during each stage of learning by 2. Since the errors made by each group to only half the stimuli are being considered in each of the graphs, this procedure permits a direct comparison to be made. An even greater difference in errors of generalization occurs between the stimuli which were, and the stimuli which were not, involved in the preliminary training of a particular discrimination.

According to these results, the effect of preliminary training is apparently to reduce the degree of generalization to the stimuli on which training is given and thus to bring about a significant reduction in errors made to these stimuli during the final training. The stimuli to which preliminary training is not given, on the other hand, begin the final learning of the total task with an initial handicap. By far the greater proportion of errors during the early stages of learning are made in response to the stimuli on which no predifferentiating training has been given. The learning of the final task following such preliminary training seems to be largely a matter of bringing about a reduction in gen-

eralization which occurs primarily to the stimuli on which training has not been given.

These results may be considered as offering additional evidence of the effectiveness of our hypothesis. Not only is the result of predifferentiating training seen to be the reduction of generalization during final training, but the generalization so reduced is more or less specific to the stimuli on which initial training has been given. The final learning begins with a degree of generalization largely confined to the stimuli on which no preliminary training has been given. As the learning of the final task proceeds, this generalization is reduced, and ultimately the differentiation of stimuli on which training has not been given becomes established. When this has occurred, the learning of the total task is on its way to completion approaching a steady level of performance.

Plateaus.—The results which indicate the way in which errors vary during the course of the final learning, as dependent upon the amount of preliminary training on a component task, suggest an additional implication with regard to the way in which plateaus occur. As is the case with many motor skills of the type studied in the present investigation, the usual measure of learning, a time score, is influenced by the number of errors which occur. Our measurement of the time of reactions on any given trial is increased in value if errors have occurred while the subject is making his response. Such time scores, when they are plotted to indicate the course of learning as in Fig. 2, may in certain instances exhibit periods of relatively little increase in learning. An examination of Fig. 2 reveals such flat places in the graphs of learning obtained in the control group and in the group having 10 trials of preliminary practice, whereas such plateaus do not clearly appear in the learning graphs of the other groups. The information which we have concerning the occurrence of errors during the course of learning suggests that these periods of little improvement are directly related to the occurrence of periods of maximum generalization. Considering the learning curves of Fig. 2 in relation to the error curves of Fig. 3, it may be seen that after an initial increase in learning, the curves of the zero- and 10-trial groups exhibit a plateau which is ended at the same point at which the sharpest drop in error score occurs. In the control group, this point is approximately in the interval of trials 31 to 40, and in the 10-trial group, approximately in the interval of trials 21 to 30. It seems probable that in these cases the plateaus which may be seen in the learning curves were ended when the high error scores produced by generalization passed through their respective maxima, and the differentiation of the subordinate skills began to take place. The relation of this finding to the hypothesis of Bryan and Harter (7, 8) with respect to lower and higher order skill has already been mentioned. In Group 30, where the points of maximum generalization as indicated by errors occurred very early during the course of final learning, we find no such period of little progress followed by a sharp increase in learning. Likewise, in the 50-trial group, where a point of maximum generalization cannot be seen clearly in error scores, we again find steady progress in learning uninterrupted by the occurrence of a plateau.

Discussion

The results of the present experiment give support to the idea that the acquisition of certain motor skills, which are complex in the sense that

they involve a number of discriminative reactions to a number of different stimuli, may be understood in terms of the interfering and facilitating effects of the reactions which make them up. These transfer effects, as previous investigations have suggested, are influenced both by the degree of similarity existing between the components, and by the amount of practice which is devoted to each. The more similar the stimulus elements which are to be associated with different responses become, it may be expected that the greater will be the degree of interference between the components of a skill, and consequently the more difficult will be the acquisition of that skill. The effect of variation in similarity of the response elements is not so well known (cf. **20**, p. 419).

The second factor, degree of training on the component reactions, may be conceived to have two different effects on the learning of the skill, according to our results. The first is the usual result of practice: the particular component reaction is increased in strength (sureness and speed of occurrence) as a result of an increase in the number of rewarded repetitions. The second effect of increasing practice on individual reactions is a more complex function. What we have called the tendency to generalize, i.e., the tendency for a stimulus to evoke, without direct practice, reactions to other stimuli which resemble the original, is an effect which our results indicate to increase at first, to reach a peak, and subsequently to decline as practice is continued. The ease of learning a complex skill is therefore conceived to depend, throughout its course, on the amount of previous practice which has been devoted to each of the components. If such practice has been relatively small in amount, the effect in a particular skill may actually be to slow up the learning of the total complex skill, particularly during the early stages of acquisition. As the amount of previous practice on one or more components is increased, however, the learning of the total skill is expected to be made easier to the extent that the specific response has been increased in strength by practice, and also to the extent that the tendency of practiced components to generalize has undergone a reduction.

The total ease or difficulty of learning the complex skill does not give the whole picture of what is conceived to be affected by the facilitating and interfering effects of the components. Both similarity and degree of previous practice may also affect the rate of acquisition of a skill at particular stages during the course of learning. Presumably, the more similar are the stimulus elements of the task, the greater will be the tendency to interference between the components. This tendency may be expected to reach its maximum, not at the beginning of the learning of the total skill, but after practice has continued for some time. Whether or not this increased interference results in a temporary slowing up in the course of the total learning may be seen to depend, according to this analysis, on the strengths of the generalized tendencies relative to the increases in strength of the component reactions which have resulted from rewarded practice. Presumably, the more similar the stimuli are which must be associated with the different reactions making up the skill, the greater will be the tendency for a genuine plateau to occur. In any event, the increased interference should be capable of being measured as an increase in overt errors, as our results and those of E. J. Gibson (**14**) indicate.

When the conditions of similarity are such that plateaus do appear, the present results indicate that they may be eliminated when a sufficient amount of previous practice has been devoted to the

component reactions, before the beginning of acquisition of the total skill. When only 10 trials of training were given on one of the discriminations involved in the skill of the present study, the curve of acquisition of the total skill which followed this preliminary training exhibited a plateau similar to the one found when no preliminary practice was given. With greater amounts of preliminary practice, the curves of learning showed no such plateaus occurring at points in the learning at which maximum interference also occurs. This finding, too, is consistent with the notion that tendency to generalize at first increases and later decreases, as a result of continued practice on the component reactions.

Additional support to this interpretation is provided by the results which indicate that the errors made during the initial period of the learning of the total skill include a much higher proportion of errors made in response to the specific stimuli on which the subject has not been trained than they do of errors made in response to stimuli which were presented during the preliminary training on component reactions. Apparently the reduction in tendency to generalize which results from sufficient practice on components is to a large extent specific to the stimuli which have been employed in the preliminary training. The stimuli which have not been used in component training exhibit a high degree of tendency to generalize, as measured by errors, during the early stages of learning the total skill.

This line of reasoning suggests the importance of another type of error analysis which was not used in the present experiment simply because no provision was made for it in the beginning. If, as our results seem to show, the result of a sufficient amount of training on one of the discriminations required in a complex skill is to reduce the generalization tendencies of the stimuli on which training is given, it may also be expected that during the learning of the total skill, fewer errors would occur in the dimension of similarity along which lie the stimuli included in the preliminary training than in the dimension which has not been used in differential training. In terms of the skill described here, this would mean that subjects who are given preliminary training on an up-down discrimination should exhibit fewer up-down confusions than red-green confusions during the learning of the total skill. Since only total number, and not type, of errors was recorded in the present study, our data do not permit this comparison. It is expected that a modification of our apparatus will enable us to make such an analysis of errors in a future experiment.

Insofar as the problem of learning by parts and wholes has been examined with tasks which are non-serial in nature, it may receive some rather oblique illumination by the results of this experiment. The idea that the efficiency of part learning suffers in comparison with that of whole learning because of the interference which occurs when the parts are finally practiced together has been advanced by a number of investigators, among them Crafts (11), Brown (5), Clark and Worcester (9), and Cox (10). This suggestion is entirely consistent with our discussion of the relation between transfer and the factors of similarity and amount of practice. It seems likely, too, that the amount of superiority found for one or the other method may depend primarily upon the operation of these two factors. If the total task is composed of stimulus elements which are very similar to each other, and if only a small amount of part training has been devoted to each component, it would not be surprising, in the light of our results, to find that under such conditions the learning of the whole task is slowed because of a high degree of interference. On the other hand, if the stimuli are quite dissimilar, and more than a small amount of practice has been given to each part, the parts may 'fit together' with a great deal of ease. It is even conceivable that particular combinations of 'part' and 'whole' training might under such conditions be found to be more efficient in terms of trials than training which began and continued on the whole task. Although this problem is not the specific concern of the present

study, the results which indicate a high degree of positive transfer to the total task following 30 and 50 trials of preliminary training on only one of the two discriminations involved seem to be of considerable pertinence.

As a whole, the results of our experiment may be taken to indicate the usefulness of considering the problem of the acquisition of complex skills as one of analyzing the interactions between the component activities of which they are composed. Since there is in existence a fairly large number of well-established facts with regard to the learning of simple habitual responses (15), it would seem both desirable and necessary to take these facts into account in situations which are called complex because more than one response is being learned. At any rate, this is a possible way of attempting to systematize the phenomena of motor skill acquisition. Whether it is an adequate way can be decided when more of its predictive potentialities are made apparent.

Summary

An experiment is reported which deals with the determination of the extent to which transfer of training takes place to the learning of a complex motor skill when varying amounts of initial practice have been given on a task which is itself a component activity of the skill. Five matched groups of subjects, each containing 30 young Navy enlisted men, were used in the experiment. Each group learned a motor skill involving four differential manual responses to four lights after having practiced a preliminary task which was part of the total skill for 0, 10, 30, or 50 trials. Part training on the discrimination of reactions to upper and lower positions of the light stimuli was given to three different groups for 10, 30, and 50 trials; and part training on the discrimination of responses to red and green lights was given to one group having 30 practice trials. Following this preliminary training, the total skill involving both up-down and red-green discrimination was practiced throughout 60 trials. A control group learned the total skill without any preliminary practice. The learning of the skill was measured in terms of time required for each correct reaction and in terms of number of errors.

1. The group having 10 trials of preliminary practice shows no significant difference in the rate of learning from that exhibited by the control group. The learning of the total skill in the groups having 30 trials of preliminary practice indicates a considerable degree of positive transfer. An even greater amount is exhibited by the group having 50 trials of such practice. No significant differences are found in the final learning of a group having 30 trials of preliminary practice on red-green discrimination, and of a group having 30 trials of preliminary practice on up-down discrimination, when the final task required both these discriminations.

2. The number of errors made by the group having 10 trials of preliminary practice is greater in the final learning than that of the control group. In the case of the groups having 30 and 50 trials of preliminary training, the number of errors is progressively reduced below that of the control group. As the number of trials of preliminary training is increased, the point of occurrence of maximum number of errors shifts progressively nearer to the beginning of the final learning. A further analysis of errors revels that in the groups having 30 trials of preliminary practice, by far the greater proportion of

errors during the initial stages of learning the final task are made to the stimuli which have not been used in the preliminary training.

3. The results indicate the occurrence of periods of little or no improvement (plateaus) in the learning of the total skill in the case of those groups having 0 and 10 trials of preliminary training, but no such effects in the learning of the groups having 30 and 50 trials of preliminary training. The loci of these plateaus correspond with the points of maximum interference in these groups as revealed by the curves of errors. No distinct plateaus occur in the 30 and 50 trial groups whose curves of errors reveal no clear-cut maxima throughout their courses.

4. The results are interpreted in the light of a general hypothesis which relates the learning of complex skills to the negative and positive transfer effects which are expected to occur between the component activities of which the skill is composed. It is pointed out that two important factors which affect the amount and direction of such transfer are the factors of similarity and degree of practice on the components. In the present experiment similarity was maintained constant, and degree of practice was varied. According to the hypothesis, the effect of increasing the amount of preliminary practice on one or more components of the total skill should be at first to increase the degree of tendency to generalize and later to decrease this tendency. This prediction is consistent with the finding that the amount of interference following increasing amounts of preliminary training increases to a maximum and later undergoes a decrease.

5. The relation of these results to studies of the occurrence of plateaus in the acquisition of complex skills and to the problem of part-whole learning of such skills is discussed.

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AN EXPERIMENTAL ANALYSIS OF SET IN ROTE LEARNING: RETROACTIVE INHIBITION AS A FUNCTION OF CHANGING SET

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Statement of the Problem

S's *set* is one of the basic variables in any learning experiment. Because of its generality, the concept of *set* demands experimental analysis into specific dimensions of variation. It is only through such treatment that the effect of set can be fully gauged and quantified.

In a previous study it was shown that *S*'s readiness for a particular type of retention test appreciably affects his learning behavior and that correspondence between learning instruction and retention test is a condition basic to optimal performance. On the other hand, non-correspondence between instruction and test significantly impairs retention performance (**4**). Difference in set at the time of learning and at the time of test, then, interferes with maximal retention.

Change in set has an adverse effect if this change is introduced while the learning materials remain invariant. On the other hand, change in set may have a beneficial effect if it is introduced along with a change in learning materials. If both set and materials are varied, the amount of interference among learning tasks may be reduced because of greater functional isolation. It is well known that dissimilarity of materials lessens retroactive inhibition (**6**). Dissimilarity of sets should have a comparable influence.

Such considerations lead to the expectation that amount of retroactive inhibition will be reduced if original learning and interpolated learning take place under different sets. Some previous experiments have shown that such is indeed the case (**3, 5, 8**).

In this experiment, set was varied by employing different testing procedures for the original and interpolated learning activities. Our previous experiment (**4**) had shown that instruction for a particular retention test may be considered an effective manipulation of *S*'s set.

Experimental Procedure

The materials for the original learning and the interpolated learning each consisted of 25 two-syllable adjectives. The materials were the same for all experimental conditions which varied only with respect to instructions and testing procedures. Two testing procedures (and corresponding instructions) were used: the method of anticipation and the method of recognition. All possible combinations and sequences of tests for original learning and interpolated learning were employed, yielding the following experimental design:

Group	*N*	Test for Original Learning	Test for Interpolated Learning	Retest
I	10	Anticipation	Anticipation	Anticipation
II	14	Anticipation	Recognition	Anticipation
III	11	Recognition	Recognition	Recognition
IV	13	Recognition	Anticipation	Recognition

During any one learning period, *E* read the 25 items of the list at the rate of one every two sec. The list was read through five times, with an interval of six sec. between successive presen-

tations of the list. This procedure was employed for original learning and interpolated learning alike. In every case, the learning instructions carefully specified the testing procedure to be followed.

A given test took place immediately after the fifth presentation of the word list. If the anticipation method was used, *Ss* were allowed four sec. for recalling each successive item. For a recognition test, *Ss* were presented with a list of 100 alphabetized adjectives containing the 25 learning items. *Ss* were instructed to check the items they recognized and were allowed three min. for this test.

The interpolated learning occurred immediately after the test of the original learning. The retest for the original learning was given immediately after the test for the interpolated material.

Ss were men and women students in a course in experimental psychology. All *Ss* were in ignorance of the purpose of the experiment, and groups of *Ss* were assigned to the different experimental conditions at random. A total of 48 *Ss* took part in the experiment.

Results and Discussion

The results of the anticipation tests and the recognition tests required different scoring procedures. In the case of the anticipation tests, number of items reproduced correctly, without regard to position, was obtained for each *S*. When the method of recognition was used, the number of correct recognitions minus the number of incorrect recognitions provided the score. Disregard for position rendered the two sets of scores more nearly comparable.

Table I presents the average number of items correctly recalled on the original learning tests and the retests following interpolation. The groups were well matched in their initial performance. As is generally the case, the recognition test yields higher retention scores than the anticipation test. However, the two groups tested by anticipation are not significantly different from each other ($t = .95$, $P = .32$) nor are those tested by recognition ($t = .85$, $P = .38$).

The amount of retroactive inhibition was determined by computing for each individual *S*, the percentage loss between original learning test and retest. This use of difference scores takes the correlation between initial scores and final scores into account. The mean percentage loss under the four experimental conditions may be found in Table II.

Since distributions of percentages, some of them of low magnitude, are involved, it is advisable to transform the obtained values in such a way as to make normal probability statistics applicable. The percentages were, therefore, transformed into corresponding angles, where angle = arc sin $\sqrt{\text{percentage}}$ (7, p. 381).

Inspection of Table II at once indicates that the use of different testing procedures for original learning and interpolated learning results in appreciably smaller losses on the retest. To gauge the significance of this effect,

TABLE I

Average Number of Items Retained on the Original Learning Test and the Retest Following Interpolated Learning

Measures of variability are also given.

Condition	Test for Original Learning		Retest for Original Learning	
	M	*SD*	*M*	*SD*
I. Anticipation-Anticipation	11.5	5.1	7.2	5.3
II. Anticipation-Recognition	9.6	4.0	7.5	3.8
III. Recognition-Recognition	19.2	4.3	15.4	6.8
IV. Recognition-Anticipation	20.6	3.0	18.2	4.4

TABLE II

MEAN PERCENTAGE LOSS BETWEEN ORIGINAL LEARNING AND RETEST FOLLOWING INTERPOLATED LEARNING

Angle transformations of the percentages and their measures of variability are also presented (angle = arc sin $\sqrt{\text{percentage}}$).

Condition	Obtained Percent *M*	Angle Transformation	
		M	*SD*
I. Anticipation-Anticipation	46.2	42.8	24.4
II. Anticipation-Recognition	23.5	23.6	26.5
III. Recognition-Recognition	24.8	27.8	29.2
IV. Recognition-Anticipation	12.3	14.3	14.2

an analysis of variance was performed on the angle values corresponding to the percent losses. There were three sources of variation: original learning, interpolated learning, and the interaction of the two. *F*-tests of Table III were obtained, with an error variance of 631.4, based on 44 degrees of freedom.

TABLE III

RESULTS OF ANALYSIS OF VARIANCE UPON TRANSFORMED PERCENT LOSSES

	df	*F*	*P*
Original Learning	1	2.33	>.05
Interpolated Learning	1	.02	>.05
Interaction	1	5.10	.01–.05

The testing procedure during the original learning does not in and of itself make a significant difference, nor does the testing procedure during interpolated learning *per se*. It is the interaction of the two which is the significant factor. It is the change in testing procedure which causes the amount of loss to vary significantly from condition to condition.

The relevant comparisons among the experimental groups bears out this general conclusion.[1] The difference between Groups I and II (Anticipation-Anticipation and Anticipation-Recognition) yields a *t*-value of 1.87 ($P = .04$). Comparison of Groups III and IV (Recognition-Recognition and Recognition-Anticipation) gives a *t* of 1.31 ($P = .10$). In conjunction with the significant overall interaction effect, these tests indicate that the sequence of testing procedures is an important determinant of the amount of retroactive interference.

The change in testing procedure may well be considered a manipulation of *S*'s set. Instruction for a specific kind of test leads *S* to respond to those characteristics of the learning materials most relevant to the test, to emphasize selectively those things which he expects to use on the test. *S*s expecting an anticipation test will emphasize position and intraserial cues. Those getting ready for a test of recognition disregard position and do not prepare for active reproduction of the items. It is the disposition to respond selectively to some characteristics of the stimulus situation rather than others which is the essence of *set*. Hence instruction for a specific kind of test is one way in which set can be varied.

As the results of this experiment show, change in set helps in the functional isolation of materials learned

[1] For each of the subgroups, an improved estimate of the variance is based on the error variance of the total distribution divided by the appropriate number of degrees of freedom (1, p. 96f).

successively. Any condition which decreases the interrelation between two learning tasks contributes to their functional isolation from each other, so that the responses appropriate to one task do not intrude upon those relevant to the other. Dissimilarity of stimulus materials is one such condition as the Skaggs-Robinson hypothesis makes clear (6). But functional isolation may also result from dissimilarity of sets. In most retroaction experiments, both variables may be effective. The usual procedure has been to hold set as constant as possible and to vary materials systematically, especially with respect to similarity. This study indicates that it is equally important to hold materials constant and to vary set systematically in order to specify fully the conditions of functional isolation.

Summary

The hypothesis was tested that amount of retroactive inhibition is reduced if original learning and interpolated learning take place under different sets. Set was varied by using different testing procedures for the two learning activities in an experiment following the conventional paradigm for the study of retroactive inhibition. Original learning was tested either by the method of anticipation or by the method of recognition and followed by interpolated tasks for which the same two methods of testing were used. All possible combinations and sequences of tests for original and interpolated learning were employed.

When both activities were carried out under the same set, a greater amount of retroactive interference resulted than was found when original learning and interpolated learning took place under different sets. Like dissimilarity of materials, dissimilarity of sets contributes to the functional isolation of tasks learned in succession.

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THE ROLE OF EFFORT IN THE PERFORMANCE OF A DISTANCE DISCRIMINATION

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In general the immediate stimulational product of responding may be inferred to be of a kinesthetic or proprioceptive nature. Such response-produced effects appear to serve two functions. On the one hand they may act as primary negative drive stimuli; on the other hand they may serve as cue or conditionable stimuli; and conceivably they may act in both ways at one time. Such a formulation, however, is not the only one which has been used to systematize the immediate effects of responding. For example, Hull (4) has used an inhibitory construct, reactive inhibition, in order to handle the negative motivational character of the results of working or responding. And Crutchfield (3) has used an expectancy construct, psychological potential, in order to describe the behavior of organisms with respect to the energy requirements of rewarded tasks. The conceptualization of Miller and Dollard (6) may be considered to be essentially like our own introductory statement above. They have designated fatigue to be the negative motivation derived from responding, and they have placed emphasis upon the cue and drive functions of fatigue. Since we have discussed their theoretical stand in a recent review (8), we need not repeat it here.

There is fairly convincing evidence available concerning the relationship between effort and the emergence of negative motivation. Increasing the effort requirements of a task, either by the traditional technique of massing trials, or by increasing the effortfulness of the task itself [see Mowrer and Jones (7) and Solomon (9)], appears to reduce the probability of a response being repeated. But the relationship between effort and the emergence of cue stimulation has not been so convincingly demonstrated by experiment, though it has received attention in theoretical writing. A discussion of closely related experiments may be found in the author's recent review (8), under the topic headings: 'The Law of Least Effort' and 'The Role of Kinesthesis in the Control of Behavior.' It is the purpose of this study to show that discriminative responses which depend upon response-produced (proprioceptive or kinesthetic) stimulation are greatly influenced by the effort requirements inherent in the specific discriminative responses themselves. To be specific, it is the purpose of this study to demonstrate a change in the performance of a distance discrimination by white rats, a change induced when the effort requirements are abruptly increased.

The experimental situation for the study of distance discrimination in the rat has been used before (1, 2, 3, 10). Our version of this situation is shown in Fig. 1. It consists of an elevated maze which has a long straightaway with several side alleys leading perpendicularly off from it at regular distance intervals. The task of the rat is to run a constant distance and turn off into a correct side alley where food reward is given. All important differential cues from the maze are controlled by rotation and interchange techniques, so that the rats must rely on response-produced effects as cues.

[1] Part of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Psychology Department, Brown University. The writer wishes to express appreciation to Professor Harold Schlosberg for his kind assistance. This work was performed while the author was an NRC Predoctoral Fellow.

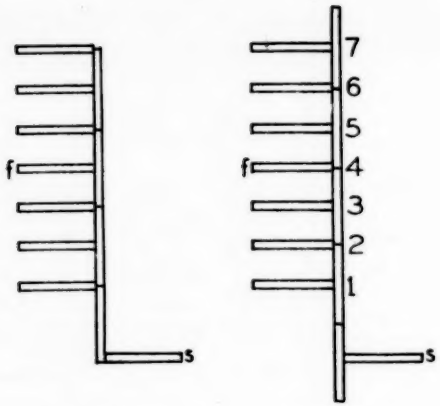

FIG. 1. A schematic diagram of the equivalent mazes used for a distance discrimination

In such a discrimination situation, we shall ask: Is the effortfulness of the locomotor response one of the more relevant variables in the control of the rat's discriminative behavior?

The experimental work directly related to the problem of distance discrimination in rats appears to be limited to three studies. Brown (1) invented the distance discrimination maze in order to study the role of kinesthesis in the stimulus-neural control of behavior. He (2) found that rats could learn to run a maze such as that shown in Fig. 1 with an accuracy exceeding chance expectations. The distance which had to be discriminated, without exteroceptive cues, was determined by the placement of food at the end of a given side alley; some variability of the rats in running the required distance indicated a substantial 'uncertainty interval' where many errors were made. Brown reported that rats whose spinal cords had been partially severed, so as to interrupt the dorsal columns in the cervical region, could learn the distance discrimination as well as did normal rats. Brown was convinced, nevertheless, that the habit was mainly controlled by response-produced effects. Therefore he concluded that the lesions of the dorsal columns were evidently inadequate in interrupting all of the avenues of proprioceptive transmission.

The distance discrimination maze was used for different purposes by Crutchfield (3). He was interested in the motivational aspects of the problem, as well as in the 'expectancies' of rats with respect to energy-expenditure. He found that if rats had learned the distance discrimination under conditions of constant hunger drive, increasing the drive would make them run further down the straightaway before turning into a side alley. To Crutchfield this meant that the rats were operating on the basis of a postulated 'psychological distance.' This psychological distance was measured indirectly by the locomotion distance traversed by the rats before they turned off from the straightaway into a side alley. Psychological distance was assumed to be a function of psychological need (in this case, hunger), as well as a function of 'psychological potential' or the 'expectation' of the rats with regard to the work requirements of the discrimination habit. Crutchfield's concepts have no physiological reference, are behaviorally defined, and are measurable by indirect means. It is interesting, in this connection, to note that Crutchfield's concep-

tual scheme can have little to say about Brown's experimental data, because of the absence of any intervening variables with a physiological reference.

Another experiment, employing essentially the same maze situation used by Brown and by Crutchfield, was that of Stellar, Morgan, and Yarosh (10). These investigators trained rats in the distance discrimination, and after the maze was mastered to a reasonable criterion of accuracy the rats were subjected to cortical lesions. It was found that the animals with lesions of the frontal areas of the cerebral cortex suffered a deterioration in the discrimination habit. The authors concluded that normal rats perform the distance discrimination on the basis of the 'symbolic process,' a process which was postulated by Hunter (5) in order to explain the performance of organisms in the delayed-reaction and double-alternation problems. According to the definition of the symbolic process which is usually employed by Hunter and others, this process is a substitute one, probably involving surrogate responses like counting; it can arouse a selective response; and it can be recalled after periods of absence. Providing that we can show that the successful performance of the distance discrimination involves a learned constant temporal delay factor, we might be able to invoke the symbolic process to explain the behavior. And to the extent that the discrimination is based upon the 'counting' of the side alleys by the rats, we can also legitimately use the symbolic process without violating its properties. But inasmuch as Stellar, *et al.*, as well as others, have shown that rats in the distance discrimination maze neither 'count' the side alleys nor make a discrimination based upon temporal delay, it would appear that the concept of symbolic process was not appropriately used. Probably the traditional feeling, that if there are symbolic processes they ought to be located in the frontal areas, was an important factor in the type of conceptualization used by these experimenters. Actually, what we can say with safety at the present stage of our knowledge is that the frontal area lesions disrupted the performance of a habit which is probably chiefly controlled by response-produced stimuli. Whether the integration of proprioceptive impulses is essentially a function of the frontal areas is still left open to conjecture.

The distance discrimination is admirably suited to a study of the relationship of effort to discriminative behavior, since it can be established in animals with fairly adequate control of cues which are not response-produced. If we are satisfied that work or effort determines to some degree the activity of the peripheral proprioceptive system, and if we can show that alterations in effort will change the characteristics of the performance of rats in the distance discrimination maze, then it is possible to link the proprioceptive system with distance discrimination behavior. This approach may be considered to be an alternative to the method used by Brown (2) to establish the role of kinesthesis in the distance discrimination. Brown's method of nerve section is a method of exclusion, while the approach we follow uses the intact organism and changes the inferred stimulation level by altering work requirements. In both cases the discrimination performance of the animals is used as the indicator of the functioning of the system largely mediating response-produced effects.

Subjects, Apparatus, and Procedure

The subjects in this experiment were 10 naive albino rats, of Wistar stock, from the Brown University rat colony. There were five males and five females. They were taken from the colony at 110 days of age.

The apparatus is shown schematically in Fig. 1. It consisted of two equivalent forms of a distance discrimination maze. These mazes were essentially the same as those used by Brown (2), Crutchfield (3), and Stellar *et al.* (10). Each form of the maze was composed of blocks which were 30 in. long, 12 in. high, and $1\frac{3}{4}$ in. wide.

The blocks were of hard wood, sanded smoothly on the narrow running surface. The maze, when assembled in either of the two forms shown in Fig. 1, always presented the same distance from the starting point, s, to the food cup, f, which rested at the end of the fourth side alley. This constant distance was composed of the 30 in. in the starting alley, 75 in. in the straightaway, and 30 in. in the side alley. The two forms of the maze were used in order to control differential cues from the junctions of the blocks in the straightaway; thus, using Maze A, the junctions came at different places with respect to the particular side alleys than they did with Maze B.

The whole maze was assembled, in either form, on a large, wooden platform, 3½ by 10 feet. This platform was mounted on casters, so that its position in the experimental room could be changed. The individual blocks which composed the maze pattern could be rotated and interchanged with one another without disturbing the pattern of each maze form. The experimental room was approximately 15 by 30 feet, and the living cages of the rats were located in a constant position at the end of this room.

The rats were fed in the maze situation by means of a small ringstand which held a shelf just large enough to support a small food cup (mason jar cover). The ringstand rested on the floor of the room, and it was adjusted so the food cup was 1¼ in. below the level of the running surface of the maze. The ringstand was placed against the end of the fourth alley when a rat was to be fed.

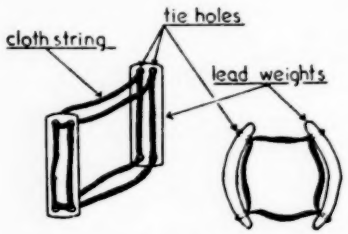

FIG. 2. Two views of the saddle-pack harness for loading rats

The apparatus was supplemented late in the experiment by the use of a so-called 'saddle-pack' harness which was designed to load down the rats. Two views of this harness are shown in Fig. 2. It consisted of two curved lead weights and cloth string. The weights were drilled with tie holes at either end, so that the cloth string harness was adjustable to each rat. The harness was weighted with 60 gm. for the males and 50 gm. for the females; this ratio of weights was based on the experimenter's estimates of the relative 'difficulty' of the task for males and females. No difficulty was encountered in using the harness; it was slipped over the rat's head, and then, by pulling both of the forepaws through the harness the load could be rested securely over the rat's shoulders and ribs. The rats were very tame and well-motivated, so they did not struggle or 'fight' the harness.

The procedure followed in training the rats was as follows. When 110 days old, the rats were placed on a 24-hour feeding schedule for a period of seven days. During this time the rats were handled, 'gentled,' and carried about the experimental room before they were fed Purina Laboratory Chow mash. They were fed in cages at the opposite end of the experimental room from the living cages. They became very tame. On the eighth day, when 24 hours hungry, each rat was placed at the starting point, s, of the discrimination maze; the starting position of the rat on the maze was facing away from the axis of the maze straightaway. The ringstand, with a small cup of mash, was placed at the end of the fourth side alley, at position f. Each rat was allowed time to explore the maze, find the food, and eat for two min. Then it was removed from the maze and placed in the familiar feeding cage where it was allowed to eat until satiated. This procedure was repeated every 24 hours over a period of 30 days. During this period all of the side alleys except the fourth, or correct, alley were separated from the straightaway by gaps which were progressively diminished. On the first day of maze training (the eighth day of feeding schedule), the gaps were eight in., and this distance was shortened by steps of ½ in., and then ¼ in., from day to day. By the 23rd day of training, all alleys were in contact with the straightaway of the maze, as shown in Fig. 1. This procedure made it possible for the rats to run the maze perfectly during the early part of training. It was learning by 'putting through.' The first errors appeared only after the gaps had been reduced to four in., on the ninth day of training. During the first 30 days of maze experience, the two forms of the maze, A and B, were presented in double-alternated order from day to day.

On the 31st day of training two changes were made in the procedure. (1) The food cup, which always had been placed at the end of the fourth alley at the start of a trial, now was kept at various places in the experimental room in order to control olfactory cues; the ringstand and foodcup were quietly slipped into place at the end of the correct alley *after* the rat made an entry into the correct alley. (2) The second change in training procedure involved the addition of trials to each daily session. Where heretofore each rat had been given but one trial per session, and so had

been allowed to make many incorrect entries in finding the correct alley, each rat was now required to make a perfect run before it was removed to the feeding cage. This requirement often necessitated several runs per daily session. The rats were allowed self-correction on each erroneous run, as in the first 30 sessions. But the last rewarded run of each session was always a perfect discriminatory response; that is, the rat had to run directly from the starting point to the food at the end of the fourth alley before it could be removed from the maze to the feeding cage. This procedure was found to aid the rats in making the discrimination. It also made it clear that the best measure of discriminatory behavior was the first entry into an alley made on the first trial of a given session; it was the simplest measure of retention of the performance of the perfect run made on the last trial of the previous day's session. The new training procedures were used from the 31st day on the maze until the completion of the experiment on the 77th day.

On the 71st day of maze experience all rats were run with the saddle-pack harness on. On the 72nd day the rats were run without the load. Thereafter, days with the load and days without the load were alternated through day 77. During these test sessions only maze form A was used.

The problem of stimulus controls was considered from the first day of training. The maze platform was rotated at least 30 degrees from day to day. The maze blocks were rotated and interchanged within the maze between the trials of each rat. In addition, the running surface of the maze blocks was wiped off daily with a strong disinfectant, as an additional control of differential olfactory cues. In a preliminary experiment it was determined that, using the rotation and interchange procedures, blind rats and normal rats were equally proficient in learning the discrimination. This agrees with the fact that among the experiments of Brown (2), Crutchfield (3), and Stellar *et al.* (10), cases may be found where blind rats and seeing rats yielded essentially the same learning rates and characteristics. However, in our preliminary experiment, the seeing rats ran faster than did the blind rats, so the present experiment was conducted with normal rats. Controls, such as putting the food cup on top of alley four, showed that our rats were not depending on vision for the differential cues necessary for making the distance discrimination. Tactual cues were probably controlled by means of the rotation and interchange procedures, and by means of frequent changes in the position of the maze on the wooden platform. Auditory cues were scrambled by the rotation of the platform from day to day. Apparently the only remaining differential cues for the discrimination were response-produced ones.

Results

It is not necessary here to present the entire course of the acquisition of the discrimination over the 70 days of training. Suffice it to say, the rats began the performance on the maze with great variability, but after approximately 50 days of training the mean ordinal number of the side alleys first entered on the first trial of a session reached a stable value of about 3.0; i.e., they tended to enter the third alley. Thereafter this value did not vary much, while the day-to-day variability of individual performances decreased slowly. The mean of 3.0 (see the location of alley three in Fig. 1) showed that the rats, taken as a group, were 'underestimating' the distance to the correct alley. Their responses were, on the average, anticipatory in nature. The average error, after a stable mean had been attained, was approximately 1.0.

It should be noted with reference to the measure used here to describe the behavior of our animals that the ordinal numbers of the side alleys may be translated into distances if one wishes to do so. Thus, the mean of

TABLE I

Ordinal Number of Side Alley First Entered by Rats on Sample of Six Training Sessions

Rats		Session (day)						Means
		65	66	67	68	69	70	
♂	1	4	4	4	4	3	3	3.7
	2	3	2	3	4	3	4	3.2
	3	2	2	4	3	2	4	2.8
	4	1	3	2	5	1	3	2.5
	5	3	4	4	3	3	3	3.3
♀	1	3	4	2	3	2	4	3.0
	2	2	3	1	1	2	2	1.9
	3	3	3	3	3	3	3	3.0
	4	3	2	4	3	3	2	2.9
	5	5	3	3	4	4	3	3.7
Means		2.9	3.0	3.0	3.3	2.6	3.1	3.0

3.0 represents a mean distance of 60 in. traversed along the straightaway before the left turn is made. Perfect performance for all rats would yield a discrimination distance of 75 in. along the straightaway, and an average error of zero.

The mean ordinal number of the first alleys entered by all rats in our sample is given in Table I, for days 65 through 70. These values may be taken as an index of the performance under normal conditions of effort. The mean ordinal number (see Fig. 1 for the appropriate ordinal numbers for each alley) of the alleys first entered on a given session during these days was 2.98. The average error was 1.04. In addition, the individual responses are presented in Table I, in order to demonstrate the variability about the mean performances. Since inspection showed little difference in performance between males and females, or between Maze A and Maze B, these two variables are omitted from the analysis.

On the 71st day, it will be remembered, all rats were run with the harness on, under conditions of increased effort. Table II presents the individual and mean responses during the test series when days with load and without load were alternated. In addition, it may be seen that the data in Table II have been paired off in groups of two days each. This was done in order to demonstrate any trends which might have taken place during the test series (days 70 through 77). The means for the 'day-pairs,' or 'session-pairs,' are given below the means for the individual days in Table II. An analysis of variance for these data is presented in Table III. A graph, showing the mean responses

TABLE II

ORDINAL NUMBER OF SIDE ALLEY FIRST ENTERED BY RATS DURING THE EIGHT TEST SESSIONS

Rats		Session—Pairs								Means	
		1		2		3		4			
		Session (day)									
		70	71	72	73	74	75	76	77		
		Level of Effort									
		Normal	Load	Normal	Load	Normal	Load	Normal	Load	Normal	Load
♂	1	3	3	3	2	4	4	4	3	3.5	3.0
	2	4	3	3	3	5	5	4	5	4.0	4.0
	3	4	3	4	2	5	4	4	4	4.3	3.3
	4	3	1	3	2	4	2	4	2	3.5	1.8
	5	3	3	4	4	4	4	4	3	3.8	3.5
♀	1	4	1	4	3	4	3	3	3	3.8	2.5
	2	2	1	2	1	1	1	2	1	1.8	1.0
	3	3	3	4	3	4	3	4	4	3.8	3.3
	4	2	2	4	2	4	3	3	1	3.3	2.0
	5	3	2	5	4	3	2	4	3	3.8	2.8
Day Means		3.1	2.2	3.6	2.6	3.8	3.1	3.6	2.9	3.5	2.7
Session—Pairs		2.7		3.1		3.5		3.3			

TABLE III

ANALYSIS OF VARIANCE OF FIRST ENTRIES UNDER CONDITIONS OF NORMAL AND INCREASED EFFORT

(Data for analysis are shown in Table II.)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	*F*	*P*
Total	79	92.0	—	—	—
Rats	9	41.1	4.57	16.93	.01
Session-Pairs	3	6.9	2.30	8.52	.01
Effort Levels	1	13.6	13.60	50.37	.01
R × S-P	27	17.5	0.65	2.41	.05
R × E	9	5.1	0.57	2.11	—
S-P × E	3	0.4	0.13	0.48	—
*Error Estimate	27	7.4	0.27	—	—

* There are some valid statistical grounds for using the second order interactions in computing the *F*-ratios for the three main variables. In such a case, the *F*-ratios would be as follows:

Rats: 7.03, $P = .01$
Session-Pairs: 3.54, $P = .05$
Effort Levels: 23.86, $P = .01$.

The second order interactions would still be tested using the triple interaction residual. The *F*-ratios above would be most conservative.

for days 65 through 77 is given in Fig. 3.

An examination of the graph shows the overall changes in mean behavior which occurred when the rats were required to carry the load. On the 71st day, the first day of added effort, the mean ordinal number of the alleys first entered on that session dropped from the former level of about 3.0 down to 2.2. This represents a decrease, in mean locomotion distance, of 12 in. On the 72nd day, when the rats were run normally, the mean response was 3.6, or a mean increase of nine in. over the stable level of days 65 to 70. In general, the rats continued to turn a little earlier in the

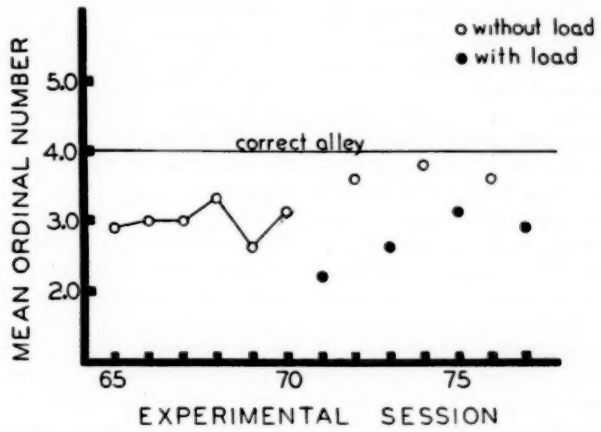

FIG. 3. The mean ordinal number of the alleys entered under two conditions of effort

maze under conditions of increased effort for the rest of the test series. The difference in behavior under conditions of increased effort is shown to be significant (see Table III). The upward trend of the mean values over the whole test series is a striking aspect of the data. This trend is significant (see Table III). The significant differences between individual animals is consistent with the experimenter's observations that the animals tended to adopt individually characteristic modes of behavior in learning the discrimination. It should be noted, however, that while the individual rat means in Table I did differ significantly among themselves, the means for the separate experimental sessions did not do so. This indicates that a relatively stable level of discrimination learning had been reached prior to the introduction of the added effort requirement.

Discussion of Results

We have demonstrated that increasing the work requirements of a rat will make it turn earlier in the maze shown in Fig. 1. This maze requires a discrimination based mostly on cues derived from the distance which the rat has to run. This shift in discriminatory behavior might be explained in several ways, as follows:

1. *Disruption.*—We could argue that the great change taking place on day 71 was the result of general 'disorganization' induced by the saddlepack harness. Several considerations make this interpretation weak. First, the rats showed little sign of emotion. There was no defecation, urination or 'fighting' of the harness. In fact, the only change, aside from discrimination shift, noted on day 71 was a lengthened running time for the rats as a group. Secondly, the discrimination was changed in an orderly manner. If there were a general disruption of behavior, we would expect the choices of the rats to be scattered over the whole maze. Instead, the only shifts taking place were in the same direction, indicating a lawfulness not implied in the concept of disruption or disorganization. In the third place, disruption is a loose concept, presumably used as a depository for seemingly haphazard behavior. It seems best to accept some responsibility for explaining behavior by discarding the concept of disruption whenever possible.

2. *Inhibition of delay.*—It might be argued that the rats turned into the nearest side alley when a certain time elapsed after they left the starting point of the maze. This would be a discrimination based on a temporal delay period. Introduction of the weighted harness would then result in slower running, and the rats would turn earlier in the maze. This explanation seems to have specific weaknesses, however. First, as has been mentioned, Stellar *et al.* (10) have shown the difficulty of correlating running time with alley choice; we have found running time to be extremely variable with a stable distance discrimination. Secondly, in view of the work of Hunter (5) and others on delayed reactions, it would appear that rats would be poorly equipped to make temporal delays of the type required in the distance discrimination maze.

3. *Psychological potential.*—Crutchfield's formulations seem to handle our particular results adequately. In terms of 'expectations' of energy expenditure, psychological potential would become exhausted sooner, or used up more rapidly, when the effort level is increased, and so the rats would be expected to turn earlier in the running sequence. Since hunger,

or psychological need, was kept relatively constant in our experiment, it need not come into the present argument.

4. *Reactive inhibition.*—The data could be viewed from the standpoint of work-inhibition theory. Using the postulates of reactive inhibition as stated by Hull (4), we could assume that the rats learned to run a certain distance and then turned left after a certain amount of inhibitory potential had been built up. Since reactive inhibition is assumed to be generated more rapidly when the work requirements are increased, the crucial amount of reactive inhibition which might serve to liberate the left-turning response would be accumulated with fewer running responses under conditions of added effort. Thus the rats should turn earlier in the locomotor sequence. Such a formulation explains the discriminatory shift on day 71.

5. *Stimulus-neural control.*—In terms of concepts which are peripheral in nature, the data can be handled very well. Assuming that the constellations of drive and cue stimuli, derived from responding, accompany the maze performance of the rats, several deductions follow. The running response is probably elicited by stimuli accompanying placement on the maze and handling prior to that. The running or locomotor sequence generates a constantly changing stimulation level of a proprioceptive nature. The level which is contiguous in time with the left turning responses which are immediately followed by food reward may be considered to act as the conditioned stimulus or cue for the left-turning response. When the animals are loaded down with the harness, the stimulation level which has become the cue will be reached with fewer running responses, and the animals will turn earlier in the running sequence.

Taking our theoretical alternatives as a whole, it still seems reasonable to maintain a peripheral conceptualization with some physiological reference. Obviously the higher integrative centers of the nervous system are necessary to the habit described in our experiment. But the parsimony and simplicity of a peripheral kind of formulation, along with our limited knowledge about central and higher functions, seems to indicate that we can profitably talk in terms of response-produced drive and cue stimuli, rather than inhibition, symbolic process, or psychological potential. Despite such considerations, we must remember that any one of three satisfactory theories discussed above is capable of handling our results. As a matter of fact, the three theories are not mutually inconsistent. Crutchfield uses concepts at what might be called a psychological level. Hull's formulation is at a gross behavioral level. The present writer tends to emphasize physiological intervening variables, using the proprioceptive function as a model. But it is perfectly possible that proprioceptive stimulation, resulting from effort, may be the stuff of which reactive inhibition is made. In view of the findings of Stellar *et al.* (10), the frontal areas of the rats' cerebral cortex may serve in the integration of proprioceptive stimulation. Finally, the end result may be described in terms of expenditure of psychological potential. The essential reason for the present author's bias for the peripheral constructs is that they imply interdisciplinary research. And, further, such constructs are readily available to handle results of experiments of a physiological nature (2, 10) as well as the psychological data (3, 7, 9).

In our evaluation of various theories we have considered the shift of responses taking place on day 71, the first day with added effort. We have thus far avoided making explanations of the significant 'rebound' phenomenon following the 71st day. None of the three acceptable theories handles this part of our data adequately. Fig. 3 shows clearly that some sort of adaptation, or rapid learning took place following the first experience with the added effort. On day 72, the mean ordinal number of side alleys first entered was 3.6, considerably above the stable level of discrimination for days 65 through 70. The choices on days with the load moved upward toward the correct alley, showing some sort of 'recovery.' The type of theory used by Crutchfield might assert that a new 'expectancy' about the energy requirements of the rewarded response was rapidly established. Hull's theory of reactive inhibition has a more difficult time, unless one is willing to postulate rapid relearning due to the delay of reinforcement incurred by anticipatory turning. Our peripheral formulation suffers the same qualification as does Hull's. Actually, the mystifying aspect of the performance from day 72 to day 77 is the rapidity of recovery of a fairly good discrimination, under both effort conditions. Most psychological theories do not imply such rapidity. Looking at our plot in Fig. 3 one might be tempted to talk again of disruption and rapid recovery from its temporary effects. But, as has been discussed above, we do not gain by using such a concept.[2]

The results presented in Tables II and III indicate that the performance of the distance discrimination was correlated to a marked degree with the effort level inherent in the task. The theory which best handles such a relation is still open to question.

Summary

An experiment involving a distance discrimination in white rats has been performed in order to demonstrate the role of effort in the performance of a task which is probably controlled peripherally by response-produced cues. It was found that rats, trained to a stable level of discrimination performance, shifted their distance discrimination responses when the work requirement was increased. The shift was in the direction of 'underestimating' the distance to be traversed; that is, the laden animals turned earlier than they did with no load. The theoretical implications of these results have been discussed, and the advantages of peripheral constructs have been emphasized.

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[2] This rebound phenomenon may be considered to be like a contrast effect. Fernberger (*J. exp. Psychol.*, 1920, **3**, 126–150) has pointed out contrast effects within series of psychophysical judgments which may be quite analogous to our present findings. Also Helson (*J. opt. Soc. Amer.*, 1943, **33**, 555–567) has pointed out contrast effects in perception. If we consider the present problem to be one in the perception of distance relationships or one of making judgments of distance, the contrast effect would probably include our data.

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DISCRETE MOVEMENTS IN THE HORIZONTAL PLANE AS A FUNCTION OF THEIR LENGTH AND DIRECTION[1]

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One of the motor reactions commonly involved in the operation of both military and civilian equipment is that of moving a limb (or limbs) as quickly as possible from one position in space to another. Normally, it is desired to terminate the movement at exactly the aimed-for point with a minimum of error and oscillation. The aerial gunner, for example, in tracking a moving target, is often called upon to make quick discrete movements of this sort. Thus when an attacking aircraft is suddenly perceived the guns must be slewed around to the target with the least possible delay. Similarly, during the course of actually tracking the target, observed displacements between the reticle and the target must be quickly and accurately corrected.

Previous studies of discrete movements, such as those of Craik (1), Householder (3), and Vince (5), have been oriented rather directly toward the solution of problems arising out of the gunnery tracking situation. In these experiments, the subjects were required to react as quickly as possible, by movements of the hand and arm, to sudden, visually perceived displacements of a target in space. Usually neither the direction in which the movement was to be made nor its extent were known to the subject until the instant that the target assumed its new position. The reactions were thus guided entirely by the stimulus conditions effective immediately before and during the making of the movement.

In the present study, a simpler procedure was employed in the hope that somewhat more basic data might be obtained on the factors involved in making discrete movements. The task set for the subjects was to move the limb as rapidly and accurately as possible from one fixed position in space to another. The positions were indicated by black lines on a white background. Each movement was initiated at the sound of a buzzer. All odd-numbered movements were made from left to right and the others from right to left. Through the use of this method, the subjects were aware in advance of both the distance to be moved and the direction of movement. The actual movements were made with the right hand and arm in the horizontal plane along a line parallel to the frontal plane of the body. Detailed graphic records were obtained by having the subjects move a lightweight pointer which was coupled by threads to a recording system having low friction and inertia. This made possible the measurement of reaction time, total-movement time, speed of movement, etc. The principal experimental variables were (1) distance moved, and (2) direction of movement (left to right and right to left).

[1] This is the second in a series of studies of human motor abilities being conducted under contract N5ori-57, Project 2, between the Special Devices Center, Office of Naval Research and the State University of Iowa. The material included here is a slightly modified version of Report No. 2 under that contract.

Apparatus

A schematic diagram of the apparatus which was used to record the movements and to present the stimuli is reproduced in Fig. 1. The board shown at the left (approximately 90 × 14 × 2 cm.) was clamped between two tables at a height of 95 cm. from the floor and provided the surface upon which the subjects made their movements. A piece of white, glazed cardboard, with black transverse lines at distances of 2.5, 10, and 40 cm. from the right of a central line, was tacked to the surface of the board. The distances between the central line and the other three lines served as the stimuli to which the subjects reacted. To prevent possible confusion of one line with another, two flat, triangularly shaped position markers were used. One of these remained fixed at the starting line throughout the experiment whereas the other was set at either the 2.5-, 10-, or 40-cm. line.

The system for recording the movements consisted of two endless loops of thread (12-lb. nylon casting line) coupled together through a compound reduction pulley having a 3-to-1 ratio. As can be seen from Fig. 1, one of the endless loops, with the subject's slide piece attached, passed across the surface of the reaction board, around an idler pulley at one end and around the larger diameter of the reduction pulley at the other end. The second loop passed around the smaller section of the reduction pulley and then to a second idler pulley mounted beyond the polygraph. A hot-wire stylus attached to this second loop rested lightly on the waxed paper (30.5 cm. wide) as it was drawn through the polygraph. Glass beads, inserted into holes in the sides of the polygraph, served as guides to keep the portion of the loop which carried the stylus on a line orthogonal to the line of movement of the paper. Movements of the arm (and slider) thus resulted in corresponding movements (one-third as large) of the stylus, providing a record from which the rate, form, and amplitude of the original limb movements could be accurately determined.

Preliminary work with the recording system revealed that the use of conventional single grooves on the reduction pulley resulted in slippage between the subject's loop and the recording loop. This difficulty was eliminated by cutting threads (16 per in.) in both the larger and smaller sections of the pulley. The loops were then passed around the pulley twice, and all slippage, even at the most rapid rates of movement, was eliminated. The grooves on the pulleys served, of course, to prevent the threads from piling up on themselves. Since it was desirable to have the recording system interfere with the movements as little as possible, mass and friction were held to a minimum. Calibrations revealed that the force produced by a weight of about six gm., when attached to the slider by a thread running over the idler pulley, was sufficient to cause the slider to begin moving across the board.

Because of the fact that the reaction and recording loops were made of nylon and because of the slight inertia of the pulleys it was feared that the time lag between the start of a movement

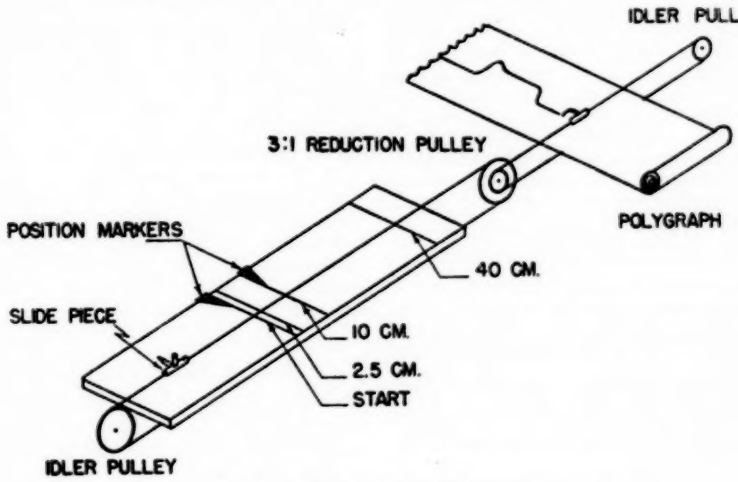

Fig. 1. Schematic diagram of apparatus

and the displacement of the recording stylus would be appreciable. When the system was calibrated, however, it was found that the time lag was only about 0.01 sec. Inasmuch as the error in reading the records was of approximately the same magnitude, it was felt that this initial lag could be ignored.

A time line was secured on the record by means of a 600-rpm. synchronous motor and a marking stylus. A raised cam on the shaft of the motor displaced a cam-follower arm once during each revolution of the shaft. Because the cam-follower was mechanically attached to the stylus, the latter was also displaced from its neutral position and produced a mark every tenth of a second. Individual time marks were separated by approximately four mm. since the paper moved through the polygraph at a nearly constant rate of 4.45 cm./sec.

The onset of the buzzer, which served as the signal to react, was indicated on the records by a second marker mechanically connected to the armature of a relay. When a telegraph key was depressed by the experimenter the relay was energized, the marker was displaced, and the buzzer sounded.

Subjects and Procedure

Twelve male students of the State University of Iowa, all of whom were right-handed, served as subjects. Their ages ranged from 20 to 27 years, their median age being 23.5.

Each of the subjects was required to make 60 reactions; 20 movements over each of the three distances of 2.5, 10, and 40 cm. All of the odd-numbered reactions were made in the left-to-right direction and all of the even-numbered ones from right to left. Two subjects were assigned at random to each of the six possible permutations of the three distances so as to equalize the possible effects of learning and fatigue.

At the start of each experimental session, the adjustable position marker was set at the correct line for the first series of 20 trials. The experimenter then sat in the chair in front of the reaction board and read the instructions to the subject who stood beside the chair. The reading was accompanied at appropriate places by careful demonstrations of the desired reactions and denotations of the slide piece, position markers, etc. The text of the instructions is as follows:

> This is a speed test. Your task will be to move this slide piece between these two markers as quickly as possible. The sounding of a buzzer will be the signal for you to move the slide piece.
>
> At the start of the test, you will grasp the slide piece with the thumb and index finger of the right hand and keep it exactly in line with the marker directly in front of you. Then, upon the sounding of the buzzer, you will move the slide piece over to the marker on the right as quickly as possible. Should your first adjustment go beyond or not quite up to the marker, continue to move the slider until it is exactly in line with the marker. When you have completed this adjustment, hold the slide piece in line with the marker until the buzzer sounds again. Upon hearing the buzzer a second time, return the slide piece to the starting marker as quickly as possible.
>
> In moving the slide piece do not drag the hand along the board; hold the hand above the board when moving the slide piece. Do not bear down on the slide piece, but slide it lightly across the board.
>
> You will continue to move from one marker to the other each time the buzzer sounds. When you have completed 20 trials you will be told to place your hand in your lap and relax. A new setting of the markers will then be made, and a new series of trials will follow.
>
> REMEMBER, THIS IS A SPEED TEST! Are there any questions?

Upon the completion of this explanation and demonstration, the subject was seated in a chair directly in front of the central starting line. The height and position of the chair was then adjusted so that when the subject's upper arm was in the vertical position and his forearm at right angles to his upper arm, the tips of his extended fingers just touched the near edge of the reaction board. The experimenter then sounded the buzzer to demonstrate the nature of the stimulus to which the subject would be required to react.

Individual movement reactions were separated from one another by intervals of approximately one, two, and three sec. arranged in random order. The timing of these intervals was not exact, being estimated by the experimenter through the use of sub-vocal counting.

The subjects were allowed to rest for approximately two minutes after the completion of each group of 20 reactions. During this interval the experimenter set the position marker to a new line according to the previously assigned testing order.

Results

Qualitative characteristics of the movements.—In Fig. 2, tracings of selected sample records have been reproduced to illustrate certain of the fairly typical characteristics of the movements. It will be noted in all of these records

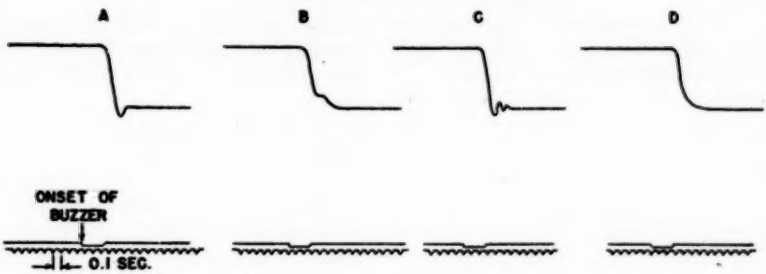

FIG. 2. Tracings of selected records of discrete movements

that the onset of the buzzer is followed after a brief interval—the reaction time—by an abrupt and rapid acceleration of the limb and a period of high and fairly uniform velocity. In some of the records there were short segments near the central part of the tracing which were so nearly straight lines as to suggest that the limb was moving at a constant velocity. But many records were sigmoidally shaped, with the initial phase of increasing and decreasing acceleration changing smoothly into a phase of increasing and then decreasing deceleration. No attempt was made, however, to study this aspect of the movements in detail.

In the majority of records, the first phase of the movement (hereafter termed the *primary movement*) ended with the limb either short of, or beyond, the terminal line. Hence a secondary adjustive movement was usually required to remove the residual error. These secondary movements frequently assumed one of the four forms shown in Fig. 2. That shown in A often occurred in the higher-speed movements. There the initial movement resulted in an overthrow which was followed by a short corrective movement in the opposite direction. In B the initial movement fell short of the mark, resulting in a brief period of zero velocity and a subsequent short corrective adjustment. In C the terminal adjustment resembles a damped oscillation, with the initial overthrow followed by oscillations of decreasing amplitude. In the movement curve of D, which was seldom observed except in the records of very slow-moving subjects, the primary-movement phase blends smoothly into a relatively long phase during which the limb gradually decelerates until the correct position is reached, neither over- nor underthrow being exhibited. Although these four types of secondary movements appeared sufficiently often to justify their selection and isolation, no attempt was made to tabulate their frequency, and other forms representing combinations of these in varying degrees were often noted. Occasionally, several corrective movements were required before the terminal position was actually reached. In general, the findings with respect to the qualitative aspects of the movements agree closely with results reported in other investigations (1, 5).

Quantitative results.—In analyzing the movement records, measurements were made of a number of different aspects of the movements. The criteria adopted in making the measurements and the results obtained therefrom are presented below for each of the more important aspects.

1. *Reaction time.*—The basic data

TABLE I

MEANS AND STANDARD DEVIATIONS (IN SEC.) OF MOVEMENT REACTION TIMES

Direction	Distance Moved					
	2.5 cm.		10 cm.		40 cm.	
	Mean	SD	Mean	SD	Mean	SD
L–R	0.26	0.09	0.25	0.06	0.25	0.06
R–L	0.25	0.08	0.24	0.06	0.24	0.06

on reaction time—defined as the interval between the sounding of the buzzer and the start of the movement—are presented in Table I. These values are all of the same general order of magnitude and agree closely with results reported by Craik (1) and by Householder (3). It should be noted, however, that these values are considerably larger than those normally obtained in studies of simple reaction time to sound stimuli. In such studies the subject's task is merely to lift his finger from a key upon hearing the sound. If his task is changed by requiring him to move some specified distance—as in the present study—his reaction time becomes longer. Woodworth (6) reports corroborative evidence on this point.

When the reaction-time data were treated by the methods of analysis of variance, with the variances attributable to distance, individuals, and direction of movement being isolated, only the component of individuals proved to be significant. From this it may be concluded that, within the limits of the present study, direction of movement and distance moved have no significant effect upon the time required to initiate a movement following an auditory signal.

2. *Primary-movement time.*—In almost all records the starting points of the movements were sufficiently abrupt so that no difficulty was encountered in their identification. The terminations of the primary movements, however, were often fairly gradual and it was necessary to adopt rigid criteria in determining these points to reduce variability in the reading of the records. Thus, a primary movement was considered terminated at (a) the point where the tracing showed a definite reversal of direction (overthrows), or at (b) the point where the tracing reached zero velocity for a period of 0.5 sec. (underthrows). If neither of these conditions was met—as in D of Fig. 2—the primary movement became identical with the complete movement. Its termination was then defined by the criterion employed to determine the end of the complete movement (see following section on Total-Movement Time).

Table II shows the means and standard deviations calculated from the measurements of primary-movement times. These statistics are listed under the three stimulus distances in spite of the fact that the mean lengths of the initial movements at these distances deviated slightly—by the amount of the constant errors—from the actual stimulus distances. The largest mean constant error ($1/N$th of the algebraic sum of the individual constant errors), however, was only

TABLE II

MEANS AND STANDARD DEVIATIONS (IN SEC.) CALCULATED FROM MEASUREMENTS OF THE DURATIONS OF THE PRIMARY MOVEMENTS

Direction	Distance Moved					
	2.5 cm.		10 cm.		40 cm.	
	Mean	SD	Mean	SD	Mean	SD
L–R	0.20	0.06	0.34	0.12	0.56	0.20
R–L	0.19	0.17	0.33	0.10	0.55	0.21

TABLE III

THE *t*-VALUES BETWEEN MEANS AND *F*-RATIOS BETWEEN VARIANCES FOR VALUES LISTED IN TABLE II

Distances Compared	Direction of Movement			
	L–R		R–L	
	*t**	*F***	*t*	*F*
2.5—10	7.90	4.00	10.11	2.04
10—40	7.12	2.78	6.57	4.41
2.5—40	8.59	11.11	8.18	9.00

* For 11 d.f., a *t* of 3.11 is significant at the one percent level.

** An *F*-value of 2.82 is significant at the 10 percent level and one of 4.46 at the two percent level with 11 d.f. for each variance.

−0.20 cm. for the 40-cm. left-to-right movements. All of the other mean constant errors were less than plus-or-minus 0.1 cm., hence they may be ignored in this connection.

From the means in Table II it appears that as the length of movement increases, the time required to perform it also increases. That this is a highly probable conclusion is indicated by the reliabilities of the differences between mean values for distances. In Table III the *t*-values[2] between the means corresponding to the different distances have been listed. All of them are significant at well beyond the one percent level. Table III also includes *F*-ratios between the variances obtained at the several distances.[3] Since the ratios between the variances at 2.5 and 40 cm. are highly significant for both directions of movement it may also be concluded that the dispersion or variability of primary-movement times increases with distance. The other *F*-ratios are not highly significant but they add additional weight to the notion that variability increases with the magnitude of the excursion.

The data of Table II also suggest the possibility that movements from left to right are slower than movements from right to left. The differences, however, are slight—only that at the 10-cm. distance being significant at the five percent level—and their consistency is probably attributable to the fact that the same subjects were tested at all three distances.

3. *Total-movement time.*—This was the time elapsing between the start of the movement and the point at which the terminal position was reached. Here too, an arbitrary criterion was used to define the end of the movement. That is, the movement was considered ended when the record line fell within a region of 0.5 mm. on either side of the aimed-for line and remained therein for a distance of 2.5 cm. Time was measured to the point at which this region was first entered.

A summary of the findings obtained through the use of this measure is presented in Table IV. There it can be seen that the mean time required to make the complete movement increased with distance for both left-to-right and right-to-left movements. The *t*-values between the means for different distances and the *F*-ratios between corresponding variances are listed in Table V. The values from these two tables lend support to the

[2] The *t*-values listed in this and succeeding tables were computed for related measures. Since this method employs distributions of differences which tend to be normally distributed, the obtained *t*'s may be interpreted in the conventional manner without regard for the fact that the variances of the original distributions differ significantly.

[3] It should be noted that the *F*-test as applied here is not an exact test of homogeneity because the variances being compared were obtained on the same subjects and hence would tend to be positively correlated. However, the presence of a correlation term would operate to reduce rather than increase, the differences between the variance for the separate experimental conditions. Thus, the test is over-conservative in the estimates it provides.

TABLE IV

MEANS AND STANDARD DEVIATIONS (IN SEC.) CALCULATED FROM MEASUREMENTS OF TOTAL-MOVEMENT TIME

Direction	Distance Moved					
	2.5 cm.		10 cm.		40 cm.	
	Mean	SD	Mean	SD	Mean	SD
L–R	0.31	0.05	0.55	0.13	0.76	0.16
R–L	0.28	0.06	0.48	0.10	0.72	0.22

conclusions drawn from the data on primary-movement time—that movement time and variability increase with distance. But this correspondence is attributable in part to the fact that primary-movement time and total-movement time appear to be positively correlated. The actual correlations between the measures for the three distances of 2.5, 10, and 40 cm., respectively, are .35, .60, and .87 for the left-to-right movements and .46, .69, and .84 for the right-to-left movements.

As in the case of the primary-movement times, there is a suggestion in the data of Table IV that left-to-right movements are slower than those in the opposite direction. This is supported by a highly significant *t*-value of 4.09 between the directional means at the 10-cm. distance. The *t*-values for the other two distances, however, yield no supporting evidence whatever.

TABLE V

THE *t*-VALUES BETWEEN MEAN TOTAL-MOVEMENT TIMES AND *F*-RATIOS BETWEEN THE CORRESPONDING VARIANCES FOR VALUES LISTED IN TABLE IV

Distances Compared	Direction of Movement			
	L–R		R–L	
	*t**	*F**	*t*	*F*
2.5—10	7.72	6.76	7.57	2.78
10—40	10.33	1.51	5.88	4.84
2.5—40	10.88	10.24	8.62	13.44

* See footnote to Table III for levels of significance.

4. *Secondary-movement time.*—A somewhat unusual feature of the data on total-movement time is the fact that although the means, as expected, are larger than comparable primary-movement means, the standard deviations are not. This can be seen by a comparison of Tables II and IV. Stated differently, adding the times required to make secondary movements to the times required for primary movements results in an increase in the means but not in the variabilities. This suggests that the variabilities of the secondary adjustments are all approximately the same and that they are relatively independent of distance traversed. Such a notion is supported by the data on secondary-movement time to be found in Table VI. The data underlying the values in this table were obtained by subtracting the mean primary-movement times from the mean total-movement times by individuals. From Table VI and from the *F*-ratios given in Table VII—none of which is significant at even the 10 percent level of confidence—it appears that the increase in distance did not significantly change the

TABLE VI

MEANS AND STANDARD DEVIATIONS CALCULATED FROM MEASUREMENTS OF SECONDARY-MOVEMENT TIME

Direction	Distance Moved					
	2.5 cm.		10 cm.		40 cm.	
	Mean	SD	Mean	SD	Mean	SD
L–R	0.11	0.07	0.21	0.11	0.20	0.10
R–L	0.09	0.07	0.16	0.08	0.18	0.08

TABLE VII

THE *t*-VALUES BETWEEN MEAN SECONDARY MOVEMENT TIMES AND *F*-RATIOS BETWEEN CORRESPONDING VARIANCES FOR VALUES LISTED IN TABLE VI

Distances Compared	Direction of Movement			
	L–R		R–L	
	*t**	*F**	*t*	*F*
2.5—10	4.00	2.47	3.15	1.30
10—40	0.19	1.21	0.71	1.00
2.5—40	3.66	2.04	4.96	1.30

* See footnote to Table III for levels of significance.

variabilities of the secondary-movement times. Also worthy of note is the fact that the mean secondary-movement times increased significantly as the distance was increased from 2.5 to 10 cm., but showed no further change between 10 and 40 cm. This may be interpreted as indicating that, beyond a certain point, secondary-adjustment times remain approximately constant in spite of increases in the lengths of the attempted movements.

5. *Speed of movement.*—From the experimental records, estimates of both the average and the maximum speed of movement were computed. The data on average speed were obtained by first calculating an average speed of movement for each individual from the mean length of his primary movements and their mean duration. This was done separately for the three distances and the two directions. The means and standard deviations of the resulting distributions of speeds were then computed for entry into Table VIII. The term *average speed* is used because the method of calculation yielded the average speed during the interval between the start of a movement and its termination rather than the instantaneous speed at any one point.

From Table VIII, it is apparent that an increase in the length of a movement is accompanied by an increase in both the mean average speed and the variability. The probable nature of the function relating speed of limb movement to distance is indicated by the lower curve of the graph reproduced in Fig. 3. There log speed (with the means for the two directions being averaged) has been plotted against log distance. Since the points fall almost on a straight line the data can be represented to a first approximation by an equation of the general form $y = ax^b$. It should be noted, however, that only three points entered into the determination, and that the true function may well be different. The specific equation for the straight line which best fits the experimental data (method of least squares) is

$$\log S = .6225 \log D + .8988$$

where S is speed in cm./sec. and D is distance in cm.

In Table IX data are presented showing the mean *maximum* speeds attained at the three distances and with the two directions of movement. In obtaining these values, straight lines were first drawn tangentially (by inspection) to the steepest portions of

TABLE VIII

MEANS AND STANDARD DEVIATIONS (IN CM./SEC.) OF THE AVERAGE SPEEDS OF PRIMARY ADJUSTIVE MOVEMENTS

Direction	Distance Moved					
	2.5 cm.		10 cm.		40 cm.	
	Mean	SD	Mean	SD	Mean	SD
L–R	13.69	3.34	32.14	9.49	78.78	23.35
R–L	14.48	5.01	33.26	9.20	79.88	22.10

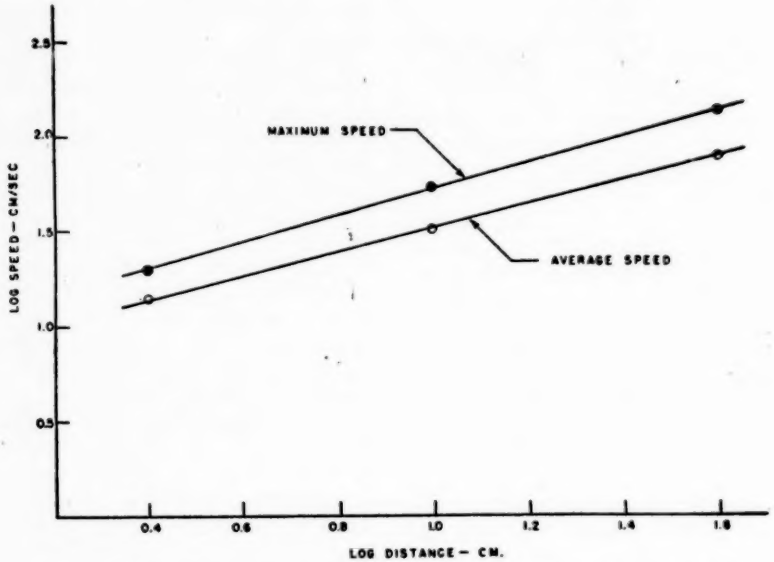

FIG. 3. Maximum and average speed of movement as a function of distance moved

the movement tracings, and the angles between these lines and the base line were then measured to the nearest one-half degree by means of a protractor. The maximum speed was computed from these angles for each reaction and a mean value obtained for the reactions made by each subject. The values given in Table IX are the means and standard deviations of these individual means.

TABLE IX

MEANS AND STANDARD DEVIATIONS (IN CM./SEC.) COMPUTED FROM MEASURES OF MAXIMUM SPEED OF MOVEMENT

Direction	Distance Moved					
	2.5 cm.		10 cm.		40 cm.	
	Mean	SD	Mean	SD	Mean	SD
L–R	19.24	5.67	52.06	17.38	136.62	39.51
R–L	19.82	7.48	53.97	17.99	138.42	40.85

As in the case of the data on average velocity, the mean maximum speeds and their corresponding dispersions show an increase with distance moved. Here too, a plot of (log speed, log distance) yields a nearly perfect straight-line relationship (see upper curve in Fig. 3). The equation for the best-fitting straight line is

$$\log S = .7040 \log D + 1.0138$$

where S and D again signify speed and distance respectively. That maximum speed definitely increases with distance is indicated by the fact that all of the t-values (not shown) between the means by distance for both left-to-right and right-to-left movements are highly significant. In addition, all of the appropriate F-ratios between the variances for distance are highly significant. There are no significant differences, however, between either the means or the variances for direc-

tion of movement. Similar findings were obtained in the case of the means and variances for average speed.

Discussion

A problem of some interest in connection with the present study is that of the relation between the duration (or rate) of a rapid movement and distance moved. At first thought, it might appear obvious that the time required to make a movement would increase with the length of the excursion. A number of workers in this area, however, have obtained evidence favoring the conclusion that as the length of the excursion increases, the speed of movement increases in proportion so that movement time remains approximately constant. Stetson (4), in an early study, found that with freely-executed rhythmic movements, such as are employed in the use of the conductor's baton, the duration of the down stroke was independent of the length of the movement. Isserlin and Freeman are cited by Hartson (2) as having confirmed this finding in the case of rhythmic movements and handwriting respectively. Craik (1) reports that the duration of a discrete corrective movement is only slightly dependent upon the length of the movement within the range of 0.63 to 11.4 cm. Householder (3), employing a similar procedure, found rate of movement to be proportional to size of excursion for movements of the order of 0.5 to 4 cm. The results of the present experiment, however, do not support the contention that the duration of a corrective movement remains the same for different excursions. While it is true that speed of movement increases with distance moved, the increase is not directly proportional to distance. The result is that the time taken to make the movement also increases. The apparent discrepancy between these results and those of previous experimenters is perhaps not as great as it might appear. Part of the difference is attributable to the fact that the range of excursions employed here was greater than in previous experiments —most of Stetson's down strokes were shorter than four cm. and Craik's maximum excursion was only 11.4 cm. With such a small range of movement lengths it would be quite possible to interpret the data as being linear when actually they may have formed a short portion of a curve. This possibility is supported by Householder's finding that the proportionality between rate and distance did not hold for movements of six to eight cm. Furthermore, although details are lacking in Craik's report, it may be assumed from his statement that an increase in distance did, in fact, have some effect upon the duration of the movement, albeit slight. It would seem most reasonable to suppose, therefore, that the duration of discrete adjustive movements most probably increases with length of the movement provided the range of excursion is sufficiently great.

Although the data obtained from the present experiment on direction of movement are for the most part inconclusive, there appears to be a tendency for the right-to-left movements to be slightly faster than those in the opposite direction. This is contrary to results obtained by Householder, who noted a slight superiority in favor of movements to the right. Since the differences are in neither case consistently significant, they may well be the result of chance fluctuations. In any event, the absolute magnitude of the differences is for the most part so small as to be of little practical importance. Where speed of movement is important, then, there

is apparently little to choose between the two directions of movement.

One of the major ways in which the present research differs from previous work is in the treatment of secondary adjustive movements. The qualitative characteristics of these terminal corrections have been noted by others but no quantitative data have apparently been previously tabulated. Because of this fact it is of some importance to examine the nature of the relationship between secondary-movement time and other measures. One rather suggestive finding in this connection is that secondary-movement time tends to be negatively correlated with primary-movement time. The product-moment correlations obtained for the three distances of 2.5, 10, and 40 cm. were −.73, −.38, and −.32, respectively—scores for the two directions of movement being combined. Although only the first of these is highly significant, it would appear that there is some tendency for short primary-movement times to be followed by long secondary-movement times and vice versa. Now since for any given distance, a shorter primary-movement time means a higher speed of movement, it follows that speed of movement should correlate positively with secondary-movement time. This is partially confirmed by the correlations between maximum speed of movement and secondary-movement time. With scores for the two directions combined, the coefficients were .57, .31, and .41 for the three lengths of movement in increasing order of size. The first of these proved to be significant at about the five percent level. It may be suggested then, that high-speed (short-duration) primary movements tend to be followed by long-duration secondary adjustments, at least for movements of the order of 2.5 cm. The fact that the correlations at the two longer distances are small, and rather easily attributable to chance, is consistent with the finding previously noted that secondary-adjustment times do not appear to increase significantly as the length of the movement is increased from 10 to 40 cm.

Summary and Conclusions

1. An investigation has been made of the speed and accuracy with which individuals can execute simple discrete movements of the hand and arm. The movements were confined to a horizontal line running parallel to the frontal plane of the body. Each movement was initiated at the sound of a buzzer and consisted simply in moving the limb as quickly and accurately as possible from one visually-perceived, fixed reference line to another. Two directions of movement (left-to-right and right-to-left) and three lengths of movement (2.5, 10, and 40 cm.) were investigated. Detailed graphic records were obtained of each movement.

2. The qualitative characteristics of the movements were found to accord closely with reports of previous investigators. The primary phase of the movement, which consists of a rapid initial acceleration and a period of high velocity, may terminate at exactly the aimed-for line, but usually does not. Hence a secondary corrective movement is required to remove the residual error. Several of the rather typical patterns assumed by these secondary movements are described.

3. The time taken to initiate a discrete movement following the onset of the auditory stimulus was found to be of the order of 0.25 sec. and to be independent of distance moved and direction. The reaction times of indi-

vidual subjects, however, differed significantly.

4. Increases in length of the movement were accompanied by significant increases in (a) the duration of the primary movements, (b) speed of movement, and (c) the variabilities of both time and speed scores.

5. To a first approximation, the equation relating speed of movement and distance was found to be of the general form $y = ax^b$, log speed in cm./sec. being linearly related to log distance in cm.

6. Evidence was obtained that secondary corrective movements are only slightly affected by increases in length of movement. Secondary-movement duration remained approximately constant for movements within the range of perhaps 10 to 40 cm.

7. No consistent differences were obtained which could be attributed to direction of movement, although there was a slight indication that left-to-right movements are slower than those in the opposite direction. The differences were too small, however, to be of practical significance.

8. There was some indication that short-duration primary movements tend to be followed by long-duration secondary movements, the effect being most marked at short excursions.

(Manuscript received February 7, 1948)

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REACTION TIME AS RELATED TO TENSIONS IN MUSCLES NOT ESSENTIAL IN THE REACTION

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INTRODUCTION

Statement of the Problem

Primary object.—The primary object of this investigation was to test Knight Dunlap's hypothesis that practice in simple reaction time (RT) results in a progressive decline in the amplitude of muscular contractions which occur throughout the skeletal musculature at the moment of each reaction. A statement of the hypothesis and its relevance to learning theory is found in the following quotation from Dunlap (**9**, p. 356):

> Learning may involve the reduction or the elimination of features of the motor pattern of a response. In some learning, this is the major, if not the only, change which occurs. The simple reaction time experiment offers a sharply defined illustration of this type of learning. The reactor, instructed to react as quickly as possible to the stimulus, and anticipating the occurrence of the stimulus at a certain moment, not only presses the key as prescribed when the flash of light, the sound, or other set stimulus occurs, but also contracts muscles in other parts of the body not immediately concerned in the action of pressing the key. Often, in the initial stages of learning to react, the motor phase of the reaction appears to be a momentary spasm of the entire external musculature.
>
> With prolonged practice in the simple reaction, the contractions of muscles which are not involved in the prescribed action progressively lessen in intensity; and some of them become unobservable, perhaps being completely eliminated. In many of the practical responses in life, the progressive elimination of superfluous or disturbing motions may be observed. The stage fright which afflicts many persons on first facing an audience disappears as the disturbing internal motor processes in the response lessen. The elimination or reduction to a negligible level of all muscular activity in certain of our perceptual and ideational responses is a similar result of practice.

The investigation was a limited test of the hypothesis, being confined to the measurement of muscular contractions, in the calf of the right leg, which occur with simple reactions to a visual stimulus over 14 days of practice.

Secondary object.—The secondary object of this investigation was to determine the relationship between the amount of improvement in simple RT and the amplitude or change in amplitude of the muscular contractions which occur in the right calf at the moment of each reaction.

Subsidiary objects. The subsidiary objects of the investigation were to determine:

1. The relationships among three attributes of these simple RTs obtained over this daily practice series of 14 days, namely speed, improvement in speed, and variability in speed.
2. The relationships among the three muscular contraction attributes, amplitude, rate of change of amplitude, and variability in amplitude.
3. The interrelationships among the three RT attributes and the three muscular contraction attributes.

History of the Problem

In placing this investigation in its proper historical context, it is neces-

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sary to note the principal parts of Dunlap's (9) hypothesis. It is maintained first of all that with practice in simple RT, improvement in speed will occur. Secondly, it is maintained that the widespread pattern of muscular contractions that occurs in reactions early in the practice series will be reduced or eliminated in the later periods of practice. The findings of investigations touching on these points constitute the essential history of the present problem.

Many references to practice effects are found in the studies of RT in the early part of the century, including those of Breitweiser (1) in his discussion of preparatory intervals in 1911, Poffenberger (16) in his discussion of the portion of the retina stimulated in 1912, and Evans (10) in his discussion of distraction in 1916. Cattell (13) found practice effects, but interpreted them as due to the reduction of the response to the reflex level.

Woodrow (21) in 1914 was very positive in his statements concerning the shortening of RT with practice. As part of his investigation of attention he obtained practice curves from 12 successive days of practice, and noted a substantial improvement in RT.

Breitweiser (1), in his discussion of the basis for variation in RT, made the following statement which seems to be in agreement with the tenor of Dunlap's hypothesis, and to indicate that the pattern of response in RT was not without consideration in this period:

Partial or weaker discharges always take place over other paths besides the ones specifically demanded by the conditions of the task. The relative strength of these accompanying motor discharges also varies from time to time, contributing to or detracting from the strength of the original reaction.

The present investigator used the incentives of knowledge of results and competition with other members of the subject group to facilitate the practice effect. Johanson (15) in 1922 was the first to bring the use of incentives to the RT experiment, and to note the superiority of performance when immediate knowledge of results was given the *S*s. His procedure was such that he eliminated the practice effect, so that the differential effect of various incentives on the rate of improvement in RT with practice has not been demonstrated although it is presumed to be the same as for performance.

Turning now to the second aspect of Dunlap's hypothesis (9), which maintains that the widespread pattern of muscular contraction occurring with reactions earlier in the practice series will be reduced or eliminated later in the series, the more recent historical context of this investigation may be observed. Davis (7) studied muscular action potentials (MPs) from the four limbs during simple voluntary motion of one of them. He found substantial potentials in all four limbs. From the results of his own work and an historical survey of the problem, he concluded that the evidence was good that "the remote parts of the excitation develop simultaneously with the focal part and as a result of the same neural process." This statement supports the part of Dunlap's hypothesis which maintains there is widespread involvement of the bodily musculature in the reaction. The investigation of this spread for the RT response has not been undertaken as a problem, although the present author in preliminary apparatus tryouts was able to obtain MPs coincident with the RT response from all four limbs, the chest, the abdomen, the back, and the neck.

In the present author's opinion, the central aspect of Dunlap's hypothesis is the reduction, following practice, of contractions in muscles not essential [1] in the reaction. There has been no previous investigation of this hypothesis for the RT performance, but the results found by several investigators, working with quite different learning tasks, such as manual pursuit, memorization of nonsense syllables, simple addition and maze

[1] Not essential here means not immediately concerned in pushing the finger down on the reaction key.

learning, offer some support. The contemporary statement of this viewpoint has been expressed by Courts (4). He agrees with the view that "at the beginning of successive periods of similar activity, the superfluous muscular tension would be expected to be progressively less."

Freeman (11) in 1931, using two *S*s, found practice in manual pursuit of a sine wave pattern resulted in a reduction to zero of the measured thickening of the muscles of all the extremities except the extremity directly involved in the response. In the same investigation, Freeman studied the changes in muscle tension in the right legs of seven *S*s who memorized nine nonsense syllables each day for seven successive days. He found a reduction in tension during each day and from day to day, as well as a reduction in the number of trials for learning.

Davis (5) in 1937 reported as an incidental finding a reduction of MPs from the right forearm with five days of practice in simple addition. In 1939, Daniel (3) reported a curvilinear relationship between MPs in all four limbs and practice, for ten trials in a simple maze. Reduction of tension occurred during the first five trials and coincided with the elimination of errors. An increase in potentials occurred in the last five trials, coinciding with a marked increase of speed in the maze. Telford and Swenson (18) also reported observations of a reduction in tensions in muscles not essential to the reaction during practice in mirror tracing. This reduction consisted of a decrease in excessive movement, twisting of the legs about the chair rungs, blinking and facila contortions.

Stroud (17), Telford and Swenson (18) and Daniel (3) investigated changes in tension of muscles essential to the reaction. This work is relevant to Dunlap's hypothesis if changes in tensions of muscles essential to the reaction were generally found to parallel the changes in tensions of muscles not essential to the reaction. Daniel (3) in his study of tensions during maze learning found such a parallel change in all four limbs. However, the generality of the parallel is not sufficiently well established to justify, in this presentation, an historical elaboration of the findings with regard to tensions in muscles essential to the reaction.

The present investigation would have been impossible without the refinements in action potential techniques which made possible the recording of potential differences as small as one microvolt. This development depended on the use of vacuum tubes for amplification of potential differences. Jacobson (14) was the first to utilize this idea in the study of muscular tensions in performance. However, Davis (4, 5) developed the amplifier technique and introduced the cathode ray oscilloscope to replace the more cumbersome string galvanometer.

The history of the problem indicates that the present investigation brings to psychology an additional study of learning, but placed rather uniquely, within the bounds of the simple RT procedure. It thereby attempts to demonstrate the role of expressed tension in muscles not essential to the reaction, in a learning task wherein the improvement desired is purely temporal as opposed to tasks involving motor coordination and memorization utilized by previous investigators. The present study also brings the technique of practice with incentives to the RT procedure where it follows upon the original investigation of incentives in RT by Johanson (15).

Experimental Procedure

Apparatus

This experiment was conducted at the psychological laboratory of the University of California at Los Angeles, during the period from August, 1942 to July, 1943. It was a period when laboratory materials, such as film, batteries, wire, etc., were subject to strict priorities, and difficulties were often encountered in obtaining a supply of film and batteries.

The problem was to assemble apparatus, and a procedure for using it, which would result in accurate and reliable measurements of the simple RT to light, and the amplitude of muscular

contractions in the right calf of each subject. The basic instruments of the assembly were an electronic chronoscope, an high-frequency amplifier, and a cathode ray oscilloscope.

Reaction time measurement.—The electronic chronoscope used in this investigation was designed by Dorcus and Hamburger (8). A quotation from the inventors serves best to describe its principle of operation:

> The instrument consists essentially of a vacuum tube voltmeter arranged to measure the potential across a standard condenser. The potential across the standard condenser results from the charge which accumulates as current flows from a standard potential source through a high resistance, to the condenser, during the interval of time to be measured.

The reaction key was a standard telegraph key wired to the chronoscope circuit to break the circuit when the key was depressed. The stimulus lamp was a single filament lamp, lightly coated with blue ink, operated from two dry cell batteries and giving six foot candles of light, as measured by Weston light meter held directly in front of the lamp. The lamp was 17 in. from the reaction key, and 30 in. from the *S*'s eye.

The major apparatus error of the experiment occurred in connection with this lamp. The *E* failed to measure the intensity of this lamp at reasonable intervals. Consequently the intensity of the stimulus light diminished approximately five foot candles from the first groups of *S*s to the last, over a period from October 26, 1942 to March 28, 1943. For this experiment the results indicate a difference of 30 msec. in the mode of RT between the RTs of the first 13 *S*s and the last 12 *S*s. This increase in RT bore a logarithmic relationship to the diminution of stimulus intensity, which is in agreement with the results of Froeberg (12). The correction of this error was made by using a Hobbs wet cell battery as the source of supply for the stimulus light, with a variable resistor in the circuit. Unfortunately this correction was not made until after the primary data of the experiment had been obtained.

Muscle tension measurement.—A standard procedure for the measurement of muscular contractions has been described in the review by R. C. Davis (6). It consists of obtaining a record of the potential difference between two electrodes, one placed on the muscle in question, the other preferably on a neutral part of the body surface of the *S*, who must be situated in an electrically shielded room or cabinet. This potential difference is fed into a high frequency amplifier which multiplies the voltage of the potential difference before it is fed into a cathode ray oscilloscope. At the oscilloscope view plate it is photographed by a motion picture camera.

The active electrode cup was placed over the center of the calf of the right leg, the point of maximum curvature, in order to register the activity of the gastrocnemius muscle. The inactive electrode was placed on the shin bone or tibia, on the front of the leg, opposite the calf electrode.

This placement of the electrodes and selection of the muscle group was fortunate in many ways. The presence of the electrode did not disturb the *S*s nor interfere with the reactions. Because there was no involvement of this muscle group in the support of the body, little general tension was found related to the posture of the *S*s, who were seated. The record obtained was clearly related to the reaction, because of the appearance and disappearance of the potential at the time of the reaction. This is not the case in records from other parts of the body, such as the abdomen and the right arm, where a more prolonged spasm occurs.

The recording camera was a 35 mm. motion picture camera, operated by the *E* by a system of strings and pulleys. The maximum speed of the camera was 10 castellations per sec., the speed used in this investigation. Exposure was continuous.

A signal input from a dry cell and rheostat to the oscilloscope, beginning 0.2 sec. before the stimulus light and ending with its presentation, indicated the point from which the time of reaction could roughly be measured on the film record. Hence the deflection of the beam at the moment of the reaction could be related with a high degree of certainty to the action potential from the leg occurring at the time of the reaction.

Controls

Reaction time.—The controls for the reliability of the RT measurements consisted of calibration checks on the chronoscope, and protection against extraneous cues by blinding board and silencers. The failure of stimulus light intensity control resulted in longer RTs for later *S* groups as the intensity of the light declined. That this actually was the case, and that the last two groups of *S*s were not simply very slow, was shown by a control practice session conducted on April 30, after the stimulus intensity had been restored to six foot candles. Inasmuch as the actual rate of decline of the stimulus intensity was not known, there was no correction of the obtained RTs for each *S* or *S* group. However, since the stimulus error was constantly in the same direction, it did not affect the relationships of RT to other variables as found in a correlation coefficient.

Action potentials.—The controls for the reliability of the MP measurements consisted of tests for the possible artificiality of the action potentials obtained and the effect of differences in leg posture on the records. The results of these tests were satisfactorily negative.

Also included in the problem of MP reliability was the reliability of the sampling, inasmuch as only six of the 100 action potentials that occurred in each practice session were photographed. Unfortunately, no direct investigation of this problem was conducted. The actual photographing of the 100 samples was not done because of the scarcity of film and anxiety lest the supply should run out in the middle of a group's practice.

Subjects

The *S*s were 25 undergraduate students enrolled in the investigator's courses in Introductory Psychology during the fall semester of 1942 and the spring semester of 1943. They were selected by a lottery at the beginning of each semester from among those students who wished to take part in the experiment. The lottery continued until 12 males and 13 females had been selected.

Running Procedure

Subjects.—The *S*s were divided into five groups. Three groups consisting of four *S*s each were run during the fall semester, and two groups of six *S*s each were run in the spring semester. Each group followed the preceding one in successive three week periods. All members of a group were run through the practice sessions in the same three weeks' period, and competed against the other members of their group. One additional *S* was run by himself as a formal check before the procedure was frozen.

Each *S* was presented with the following written instructions at the beginning of the first practice session:

> In front of you you will observe a telegraph key and a blue light on a board. You are to place the index finger of your right hand on the key. Keep it there at all times during the experiment. Let your left hand rest in your lap. Your task will be to press the key down with your finger as quickly as you possibly can, when you see the light flash on.
>
> A noise from this signal clapper will warn you that the light is about to flash on. However, do not try to beat the game. To prevent this, the interval between the signal and the light will vary. From time to time the light will not be given after the signal. Press the key down only when you see the light flash on. Press it down as quickly as you can. Hold the key down with a minimum of effort, once you have made your reaction, until you hear two signals from the clapper. This will mean that your reaction time has been recorded, and that you can let the key up for the next reaction.
>
> In attempting to make your reaction as fast as possible, attend both to the light and to the movement of your finger. There is no one way of responding which is fastest for all subjects. Do it the way which is fastest for you. Do not talk or make unnecessary movement during the series of reactions. Make any comments before or after each session.

None of the *S*s were given any information concerning the nature or purpose of the apparatus, except that the time of the reaction was measured from the break of the telegraph key circuit. The *S*s did not see any of the apparatus in the room containing the cathode ray oscilloscope, nor did they know that moving pictures were being taken. For them it was completely an RT performance test, although some thought that a preliminary blood pressure reading from the leg had been taken.

At the beginning of each day's practice session, each *S* was told his average RT of the preceding practice period, and shown a chart containing the practice curves of all the members of his group. Thus, just before each day's practice period, each *S* knew whether his previous performance was an improvement or a regression, and how he stood in relation to his group.

Barring absences, each *S* underwent 14 practice sessions, although the *S*s expected 15. The practice sessions occurred once a day, Monday through Friday, for the three successive weeks. The *S*s were dismissed after the fourth performance of the third week. Each practice session consisted of 100 recorded reactions.

All four *S*s of Group 1 were absent the fourth day of practice due to a holiday. Five other *S*s were each absent one day of the practice period. No *S* missed more than one day of practice.

Reaction time.—The *E* sat before the panel of the chronoscope. First he signaled once by hitting the clapper against a board on the table. Then he counted to a number between four and eight. At the end of the count he pulled down on the commutator handle which simultaneously closed the chronoscope circuit and the stimulus light circuit. The count of four was timed by previous practice with a watch to be two sec. and a count of eight, four seconds, so that the interval between the ready signal and the light stimulus varied between two and four sec., approximately. This procedure was followed to allow the *S*s the preparatory interval which gives

the fastest performance. In the experiments of Woodrow (21, 22), Breitweiser (1), and others, this range was found to give faster RTs than shorter or longer preparatory intervals.

The stimulus light remained on until the RT had been recorded. The interval between successive presentations of the stimulus lamp was approximately 10 sec. as timed after the *E* had become practiced in the routine. The room was in darkness except for the illumination provided by the stimulus lamp and the shielded lamp used by the *E*.

From time to time during the series of reactions, the *S* would press down the key before the light went on. Such instances were noted by the exceptionally high milliammeter reading, and were not recorded on the protocol except for an 'x' mark above the reaction number. To prevent this occurrence, the light was occasionally not presented after the ready signal. If the *S* reacted to this catch test he was warned verbally. The frequency of the catch test depended on the degree of anticipatory tendency on the part of the *S*, and the number of times he failed the catch test.

Muscular action potential.—After preliminary adjustment of the electrodes, amplifier, and oscilloscope, and a check on the *S*'s posture, the *E* returned to the experimental table and asked if the *S* were comfortable and ready. If the answer were in the affirmative, the *E* seated himself behind the chronoscope and began the RT series. At the 10th, 11th, and 12th reactions, and the 80th, 81st, and 82nd reactions, *E* pulled the string which engaged the camera clutch. Thus, a photographic record of the oscilloscope beam, and hence the MP, was obtained for the reactions so photographed. The *S* was unaware of this occurrence.

The Data

Reaction time data.—The RT data came from each practice session in the form of a protocol containing the *S*'s RTs in msec. for each of the 100 reactions. These time scores were summated and averaged. This average was recorded as the day's average RT for that *S*, the notation being Average Daily Performance RT (Av. Daily Perf. RT). This provided the basic data for the results of the investigation. In addition, the specific RTs for reactions 10, 11, and 12, and 80, 81, and 82, occurring with the photographed action potentials, were recorded separately for each *S* for each day, and noted as Specific Perf. RTs.

Muscular action potential data.—The MP data from the calf of the right leg, for each photographed reaction of each practice session, occurred as a sudden peak and drift on the film record of the oscilloscope beam, at the appropriate number of castellations from the stimulus signal on the film. An example of the film record is shown in Fig. 1. The amplitude of the action potential was defined as the distance from the middle of the 60 cycle base line to the highest point of this peak and drift, measured on a stainless steel machinist's ruler in linear units of $\frac{1}{64}$ in. The maximum reading possible on the 35 mm. film when the scope beam was centered was 35 linear units. All potentials that went off the film (less than one percent of the data), were recorded as 35 plus. Within the amplifier calibration error of 10 percent it can be said that 35 linear units equals 42 microvolts, and one linear unit equals approximately 1.2 microvolts.

The amplitudes of the six samples for each day's practice session were averaged and recorded as the Average Daily Amplitude MP (Av. Daily Amp. MP) of that *S*. In addition, the specific amplitudes of the six samples were recorded separately as Specific Amp. MPs.

Analysis of the Data

Definitions of the Variables

General.—Three variables were used to describe the RTs obtained with the experimental procedure used in this investigation. Variable one is the performance

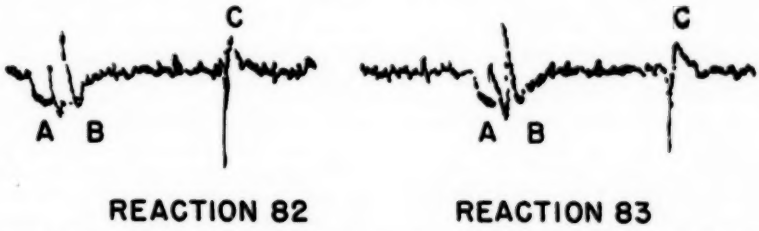

FIG. 1. Sample muscular action potential record. A. Stimulus input signal. B. Action potential at moment of stimulation. C. Action potential at moment of reaction

of the *S* at the reaction time task, denoted as Performance RT (Perf. RT). It is the speed of his reactions. Variable two is the *S*'s improvement in performance at the task, with practice, and is denoted as Improvement RT (Impr. RT). It is the progressive shortening of RTs over the practice periods. Variable three is the variability of the *S*'s performances at the task, denoted as Variability RT. It is the dispersion of his performances.

The MP variables were three variables similar to those of RT, but devoid of relation to the task set and differing in the basic unit of observation, namely amplitude, representing amount of muscular contraction, rather than time. Variable one is the amplitude of the *S*'s MP and is denoted as Amplitude MP (Amp. MP). It is the magnitude of his action potential deflection and represents the magnitude of muscular contraction at the moment of the reaction. Variable two is the increase or decline in amplitude of the *S*'s MP over the practice periods, denoted as Increment MP (Incr. MP). Variable three is the variability in amplitude of the *S*'s MPs and is denoted as Variability MP. It is the dispersion of the amplitudes.

The major emphasis in this experiment is on the total practice period of 14 days, wherein the values of the RT and MP variables for a single day's practice are the units in which the variables are calculated and the units in which the results are stated. Thus, the results for RT may be stated as answers to these questions. What is the average for 14 daily performances of each *S*? What is the improvement per day in daily performance for 14 days of practice for each *S*? What is the variability among 14 daily performances for each *S*? Hence the practice as measured in one day time units is always included either explicitly or implicitly in the results. For the general statement of results the practice inclusion is always the total practice period of 14 days. Also the general results are stated as the values of the variables for each individual *S* or the average of the values for 25 *S*s, each value calculated individually.

Specific.—The basic unit for Perf. RT is the average time in ms. of 100 trials, constituting the practice for one day for one *S*. The grand average of 14 of those daily averages for one *S* is the basic unit for the general statement of results, and for determining the relationship of Perf. RT to the other variables. It is to be remembered that an increase in Perf. RT is an increase in RT, or a slower performance.

For each *S*, Relative Impr. RT is the slope of the line of best fit for the relative Perf. RTs on practice. Relative Perf. RTs are expressed as a percent of the grand average Perf. RT for each *S*. Relative Impr. RT is the rate of change of performance with practice in percent of the mean per day units, where the mean is the grand average Perf. RT. The line of best fit is the regression line of Relative Perf. RT on days of practice; hence the slope of the line of best fit is the regression coefficient. The regression coefficient for Relative Perf. RT on days of practice is, r (Practice & Relative Perf. RT) $\times$ Sigma Relative Perf. RT/Sigma Practice. This measure of Relative Impr. RT is denoted as % Impr. RT.

This measure of improvement is the most valid measure of Impr. RT which could be found by the investigator. It utilizes all the data and therefore is less sensitive to sampling errors than measurements dependent on the differences between first and last samples in the practice series. This measure also provides comparable measures of improvement among *S*s of varying levels of performance. That is, an improvement of 50 ms. is relative to the grand mean performance of the *S*. If the grand mean performance is 250 ms., the relative improvement is low as compared with the improvement 50 ms. represents for an *S* with a mean performance of 180 ms.

With this measure the *S* has the greatest improvement whose deviations from the grand mean Perf. RT are the greatest percent of the grand mean, and whose daily relative performance most nearly

approximates a one to one negative linear relationship with days of practice.

Another, less valid, measure of Relative Impr. RT was used to obtain some index of weekly differences in improvement. This subsidiary measure was the difference between the performance of the first and last days of the practice series, expressed as a percent of the first day's performance. It is denoted as % Impr. RT (1st Diff.). This measure is not very valid because it is extremely sensitive to sampling errors of the first and last days' performance, and fails to utilize all the data. However, where variability in performance is not very great, and the acceleration of the learning curve is quite constant, this measure provides a rough index of improvement. With this measure, only two cases gave values widely divergent from those of the more valid regression coefficient measure. One was an unusually poor first day's performance, and the other, an unusually poor last day's performance relative to the other performances of those subjects. The correlation between % Impr. RT and % Impr. RT (1st Diff.) for the 25 *S*s is plus .71; P.E. = .08.

Absolute Impr. RT is obtained by converting the relative values back to absolute values. This is done by multiplying the percent value of the relative measure by the value of the grand mean, for each *S*. This procedure holds for all the relative measures.

For each *S*, Relative Variability RT is the sigma or standard deviation of the distribution of his daily Perf. RTs, expressed as a percent of the grand average performance. It is denoted as % Variability RT. This measure provides standard scores among *S*s of differing performance levels.

The basic unit for Amp. MP is the average amplitude of the six photographed action potentials which constitute the MP record for one day's practice session of 100 reactions, for one *S*. The grand average of the 14 daily averages for one *S* is the basic unit for the general statement of results, and for determining the relationship of Amp. MP to the other variables. Except for the inclusiveness of the samples, the measure Amp. MP is parallel in construction to Perf. RT. For six samples out of 100, the probable error of the mean Amp. MP of a single day is approximately four times as large as the probable error of the mean of 100 samples.

Relative Incr. MP is exactly parallel in construction to Relative Impr. RT, being the regression coefficient of Amp. MP on practice for each *S*, expressed as a percent of the grand mean Amp. MP. It is a valid measure for the same reasons. It is more precisely denoted as % Incr. MP. The major difference between the two variables is that for any given *S* Incr. MP may be either positive or negative, whereas with Impr. RT the increment for any given *S* is always negative. In relating Incr. MP to the other variables the negative signs are disregarded, and the increment is treated as an absolute rate of change in amplitude in units of percent of the grand mean Amp. MP per day. Absolute values may be obtained from relative values as before.

No other measure could be found which would give a rough measure of the increment for the purpose of indicating weekly variations in Incr. MP. The subsidiary measure, % Impr. RT (1st Diff.), could not be paralleled for Incr. MP because there was no consistent curve for Amp. MP on practice. For a given *S* the first or last day's Amp. MP might be at any point within the total range of amplitudes for 14 days.

For each *S*, Relative Variability MP is exactly parallel in construction to Relative Variability RT. It is the SD of the distribution of the Amp. MPs, expressed as a percent of the grand average Amp. MP. It is denoted more precisely as % Variability MP.

The Quantitative Distribution of the Variables

The general statement of the distribution of the quantities of the variables is to be found in Table I.[2] Perf.

[2] The data for the individual *S*s will be supplied by the author upon request.

TABLE I

THE QUANTITATIVE DISTRIBUTION OF THE VARIABLES

Part I. Reaction Time

	Perf. RT	% Impr. RT	% Impr. RT (1st Diff.)	% Variability RT
Range	172–277	−.16 to −2.83	6.1–45.5	3.04–18.02
Average	230	−1.44	25.2	9.8
SD	26.97	.72	10.27	3.25

Part II. Muscular Action Potential

	Amp. MP	% Incr. MP	% Variability MP
Range	5.0–16.7	.44–9.92 (+.59–+9.92) (−.44–−8.13)	18.0–62.2
Average	10.2	3.71	41.1
SD	3.24	2.67	10.97

RT and Amp. MP are the grand averages for the total practice period.

Special variations in practice and subject inclusion.—For the purpose of obtaining higher degrees of certainty of relationships among the variables than provided by grand average Perf. RT and Amp. MP for each *S*, three different arrangements were made. First, a distribution of all the daily averages of all the *S*s was made for Perf. RT and Amp. MP. Second, a distribution of all the Specific Perf. RTs and their related Specific Amp. MPs of all the *S*s was made. Third, a distribution of all the daily averages of *S*s within each practice group was made for Perf. RT and Amp. MP.

The means, sigmas, and their probable errors, as well as the number of measures in each of these distributions, are given in Table II.

TABLE II

DISTRIBUTIONS OF PERF. RT AND AMP. MP FOR SPECIAL VARIATIONS IN PRACTICE AND SUBJECT INCLUSION

Measure	No. of *S*s	No. of Measures	Mode	Mean	PE Mean	SD
Av. Daily Perf. RT	25	334	235	230.0	1.34	36.3
Av. Daily Amp. MP	25	334	6.5	10.14	.21	5.77
Specific Perf. RT	25	1926	240	235.6	.85	56.7
Specific Amp. MP	25	1926	5.5	10.27	.10	6.84
Av. Daily Perf. RT						
Group 1	4	52	202	194.9	1.88	20.0
Group 2	4	55	201	207.9	2.84	31.3
Group 3	4	55	232	233.5	2.09	23.0
Group 4	6	79	265	259.9	2.76	36.4
Group 5	6	81	226	237.2	2.07	27.6
Av. Daily Amp. MP						
Group 1	4	52	6.1	10.17	.45	5.16
Group 2	4	55	5.8	9.96	.47	5.16
Group 3	4	55	5.1	9.50	.52	5.77
Group 4	6	79	5.8	7.53	.28	3.67
Group 5	6	81	10.6	13.28	.50	6.69

TABLE III

DISTRIBUTIONS OF PERF. RT AND AMP. MP FOR EACH WEEK OF PRACTICE

Measure	No. of Measures	Mode	Mean	PE Mean	SD
Av. Daily Perf. RT					
Week 1	120	251	248.0	2.72	43.5
Week 2	117	218	219.9	1.66	26.9
Week 3	98	230	220.9	1.83	26.9
Av. Daily Amp. MP					
Week 1	120	8.0	8.95	.310	4.97
Week 2	117	6.5	10.41	.384	6.20
Week 3	98	6.5	11.78	.388	5.71

It can be seen that in general the Perf. RT distributions are not significantly skewed, the mode lying near to the mean. However, the Amp. MP distributions show distinct positive skewness; for Av. Daily Amp. MP, Sk. equals plus .88.

For the purposes of determining the weekly differences among the variables and the weekly differences in their interrelations, two arrangements were made. First, a distribution of the weekly values for each *S* was made for Perf. RT, Amp. MP, and % Impr. RT (1st Diff.). Second, a distribution of all the daily averages of each week for all the *S*s was made for Perf. RT and Amp. MP. The quantities descriptive of the latter distribution are given in Table III.

RESULTS

Primary Object

Does 14 days' practice in simple RT to a light stimulus result in a progressive decline in amplitude of muscular contractions which occur in the leg at the moment of each reaction? A tentative answer in the negative is seen in the general trends of the curves in Fig. 2, showing the curve of Av. Daily Perf. RT and Amp. MP on days of practice. Each day's value of RT or MP is the grand average of each day for all of the 25 *S*s. Day 4 shows a distortion of the RT curve because of the absence of Group 1 *S*s on an academic holiday.

Because of the magnitudes of the standard deviations for the single days, the differences between the value of Av. Daily Perf. RT or Amp. MP for any one day and any other day did not achieve a probable error critical ratio (CR) of four. However, by considering the changes in amplitude and performance, using the week as the unit for combining the data, this difficulty was overcome. The Av. Daily Perf. RT and Amp. MP for the three successive weeks were given in Table III.

The CR of the difference between the Av. Daily Perf. RTs of week one and week two is 8.78. The equivalent CR for the difference between Av. Daily Amp. MPs of week one and week three is 5.68. The CRs of the differences between adjacent weeks of Av. Daily Amp. MP do not meet the criterion of a CR of four. A more adequate sampling of the Amp. MPs of the 100 reactions of each practice period would have yielded lower PEs of the mean Amp. MPs and increased the chances of obtaining CRs of four or higher for all the weekly differences. These weekly data provide a less tentative negative answer to the question at hand.

The most crucial evidence for an

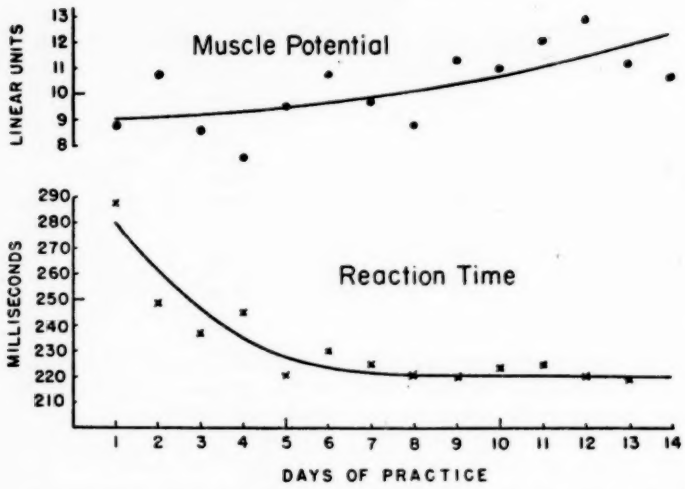

FIG. 2. The curves of Av. Daily Perf. RT and Amp. MP on days of practice

answer to the question is to be found in the results with the individual *Ss* for the variables % Impr. RT and % Incr. MP, which are measures of the rate of change in Perf. RT and Amp. MP with practice. Reference to Table I, Part I, shows that with regard to Perf. RT, improvement occurred in every case, ranging from .16 percent of the grand average per day to 2.69 percent of the grand average per day. This is in full support of the implication of Dunlap's hypothesis that practice results in improvement when the instructions to the *Ss* are "to do it as fast as you can," and is consistent with the earlier findings of Evans (10), Breitweiser (1), Poffenberger (16) and Woodrow (21).

Table I, Part II, however does not offer similar unanimity of results for Amp. MP as regards decline with practice. An increment occurred which varied in sign from plus to minus among the *Ss*.[3] A negative increment corresponds to a progressive decline in amplitude as stated in the question. The *Ss* ranged in % Incr. MP from plus 9.92 percent of the grand average per day to minus 8.13 percent of the grand average per day. However, 19 of the 25 *Ss* showed a positive increment and only six, a negative increment. Hence to the question of progressive decline in Amp. MP, approximately four-fifths of the *Ss* sampled gave a negative answer—in fact, the opposite answer to the question.

The differences among the major variables for these plus and minus increment groups were not of sufficient magnitude to be reliable, considering the small *N* of the negative group. A new experiment would be required to show whether differences among the variables for positive and negative Incr. MP groups are significant.

These results for the primary object of the investigation should only be held relevant to the conditions of the experiment, and are not to be construed as a statement of results for any other conditions of RT perform-

[3] The data for the individual *Ss* will be supplied by the author upon request.

ance, wherein improvement might be expected to occur.

Secondary Object

Is the amount of improvement in simple RT to light with daily practice related to the amplitude or changes in amplitude of muscular contractions in the leg, occurring at the moment of the reaction. A tentative answer to this question is found by correlating the values of % Impr. RT and the MP variables of Amp., % Incr. and % Variability, using the most general statement of the variables. The scatter diagrams for these correlations contain 25 points, one for each *S*, expressing the values of the correlated variables for each *S* for the total practice period of 14 days. Correlations using this number of points require an *r* of approximately .40 to be significantly different from zero; and the reliability of the magnitude of *r* as representative of other similar samples is very low.

Examination of the scatter diagrams for % Impr. RT and Amp. MP, and for % Impr. RT and % Incr. MP indicates a curvilinear relation for both. The magnitudes of these relationships are indicated by the correlation ratios, *eta* equals .59 (PE = .09) for Amp. MP on % Impr. RT; and *eta* equals .55 (PE = .09) for % Incr. MP on % Impr. RT. That these relationships are better than chance is shown by the CRs of 6.5 and 6 respestively for the two *eta*'s. However, four times the PE equals .36, which would leave the likely true magnitude of the first correlation ratio somewhere between .23 and .9.

It should be noted again that the values of % Incr. MP are used without reference to sign. Inspection of the six negative values of % Incr. MP showed that extending the % Incr. MP ordinate to the negative values did not change the position of these six values relative to % Impr. RT. This merely created a reflection of the curve on the negative side. Inspection did not reveal any clear cut relation between % Variability MP and % Impr. RT.

For these 25 *S*s the curve of relationship found for % Impr. RT and Amp. MP, or % Incr. MP, may be described as follows. High Amp. MPs or large % Incr. MPs went with either high or low values of % Impr. RT, and lower amplitudes or small % Incr. MPs went with medium % Impr. RT, the curve being continuous.

A partial check for the validity of this relationship is to be found in the correlation ratio between Amp. MP and the other measure of Impr. RT, namely % Impr. RT (1st Diff.), which is based on the difference between the first and last values of Perf. RT for the practice series, and expressed as a percent of the first. This measure, while not as valid as % Impr. RT, does not depend on the linear or non-linear attribute of the learning curve for its values. The correlation ratio, *eta*, =.73 with a PE = .06.

A further analysis can be made of the relationship between % Impr. RT (1st Diff.) and Amp. MP by determining the regression lines of the correlations between those two variables for each successive week of practice. In these weekly scatter diagrams the scatter of the points is very great, so that the correlation ratios are low, and the shape of the curve not reliable; but the change from week to week in the shape of the curve is roughly denotable by inspection. The shape of the curve for the first week is from low to high to low Amp. MP as % Impr. increases. In the second week there is a linear progression from low to high Amp. MP as % Impr. increases. In this third week there is a high to low to high sequence. Thus, there was a change in the shape of the curve for each successive week of practice. Hence it is unlikely that the relation found between % Impr. RT and the MP variables for the total practice period is a universal one for all practice periods, or relevant to any factors more refined than the total practice period and its attendant conditions.

As an answer to the question posed as the secondary object of this investigation, it may be said that for the total practice of these 25 *Ss* a curvilinear relationship having a correlation ratio of approximately .55; PE .09 exists between % Impr. RT and the two MP variables, Amp. MP and % Incr. MP. However, the number of *Ss* would have to be increased to 100 to be sure that a correlation ratio of the magnitude of at least .35 existed. Since only 25 *Ss* were used, instead of 100, the significance of the relation obtained is a matter of quite doubtful reliability for the general population of college students from which the subject sample was drawn.

Subsidiary Objects

What relationships for the total practice series exist among the three RT variables—speed, improvement in speed, and variability in speed; and among the three MP variables—amplitude, rate of change of amplitude, and variability of amplitude? Also what relationships exist between each RT variable, excepting % Impr. RT, paired with each MP variable?

The determination of these relationships, with one exception, is by the same correlation procedures as were followed with regard to % Impr. RT and Amp. and % Incr. MP in the previous section, and is subject to the same limitations. For the 25 *Ss*, under the conditions of this investigation, the interrelationships among the RT and MP variables were expressed in the values of *r* found in Table IV.

The high degree of relationship among the absolute amounts of the three variables is interpreted as an indication of the common base of the measures in the distribution of Perf. RT and Amp. MP on practice with a marked trend which equates to a large extent improvement or increment and variability, and follows the expected equivalence of amount of variability and magnitude of performance. The apparently reliable relation between % Impr. RT and Perf. RT is interpreted as resulting from unequal incentives for differing values of Perf. RT, entering through the *Ss*' knowledge of results. The parallel relationship for % Incr. MP and Amp. MP is not readily interpreted. Lacking a priori justification, the magnitude of this relationship is open to serious doubts, because of the small number of cases (25) involved in the determination of the *r*.

TABLE IV

CORRELATIONS AMONG RT AND MP VARIABLES

Variables	*r*	*PEr*
Relative RT measures		
Perf. RT and % Impr. RT	+.40	.11
Perf. RT and % Variability	+.20	.13
% Impr. RT and % Variability RT	+.64	.08
Absolute RT measures		
Perf. RT and Impr. RT	+.62	.08
Perf. RT and Variability RT	+.48	.10
Relative MP measures		
Amp. MP and % Incr. MP	+.41	.11
Amp. MP and % Variability MP	+.27	.13
% Incr. MP and % Variability MP	+.42	.11
Absolute MP measures		
Amp. MP and Incr. MP	+.66	.08
Amp. MP and Variability MP	+.80	.05

A further examination of the scatter diagrams shows the correlations between the RT and MP variables, with the exclusion of % Impr. RT, to be low and negative, or zero, and not observably curvilinear. All the zero or near zero *r*'s are of correlations involving a % Variability measure. The *r*'s for 25 *Ss* lack reliability at these low magnitudes of approximately −.25 to zero.

As a test for the validity of the highest of these *r*'s (−.29 for Perf. RT and Amp. MP), as well as to determine the effect

TABLE V

CORRELATIONS BETWEEN PERF. RT AND AMP. MP

Sampling	Practice	No.	*Ss*	*r*	*PEr*	CR
Av. Daily	Total	334	All	−.211	.035	6.0
	Week 1	120	All	−.247	.059	4.2
	Week 2	117	All	−.062	.062	1.0
	Week 3	98	All	−.158	.066	2.4
	Total	52	G 1	−.145	.092	1.6
	Total	55	G 2	−.126	.089	1.4
	Total	55	G 3	−.391	.077	5.1
	Total	79	G 4	−.284	.070	4.1
	Total	81	G 5	−.183	.072	2.5
Av. Daily and Log Amp. MP	Total	334	All	−.242	.035	6.9
Specific	Total	1926	All	−.244	.014	17.4
	Total sample (first)	970	All	−.168	.020	8.4
	Total sample (last)	959	All	−.231	.021	11.0

of the stimulus light intensity error on these correlations, a series of correlations for Perf. RT and Amp. MP were calculated, using various samplings of data less leveling in effect than the grand average for each *S*, and giving *N*'s sufficiently large to determine the validity of a low correlation. The magnitudes of the *r*'s, their PEs and CRs, the number of points used, and the nature of the sampling are given in Table V. They are also given for a final variation—the use of log Av. Daily Amp. MP to compensate for the effect of the positive skewness of Amp. MP values.

It may be concluded that an *r* of −.21 seems representative of the correlation between Perf. RT and Amp. MP with the five different groups of *S*s, giving *r*'s distributed between plus or minus four PE's of $-.21 \pm .035$. The correlation seems to be higher for slow performances than for fast ones, but the significance of this difference is not high, the CR being 2.2 for the difference between the *r*'s of the first and last samples of the specific RTs and MPs. The negligible value of the *r* for weeks two and three of the practice period, where the practice effect is lowest for RT, indicates that the general correlation of −.21 occurs primarily because of the wide scatter of Perf. RT values in the first week, and does not occur when performance has become stabilized.

The negative correlation between expressed tension and poorness of RT found in the present study is in agreement with the results of Stroud (**17**), and Telford and Swenson (**18**), who found a negative relationship between expressed tension in muscles essential to the task and poorness of performance in maze learning and mirror tracing. But the *r* of −.21 is much smaller than the *r* of −.67 found by Telford and Swenson.

Miscellaneous

Within the single day's practice session, the average of Specific Amp. MPs of the last samples is smaller than that of the first samples, and the average of Specific Perf. RTs for the last samples is higher, that is, slower, than that of the first samples. These differences of 8.6 msec. and 1.4 units Amp. MP have CRs of 6.7 and 5.2, respectively. This is the opposite of the result for successive days of practice. The former result is interpreted as a performance decrement in a work period consistent with changes in muscle action with repetitive tasks, and also consistent with the *r* of −.21 for Perf. RT and Amp. MP. Wells, Kelley and Murphy (**20**) found a similar per-

formance decrement in RT during the last half of a single practice session. However, deviations from this general result for Amp. MP appear in those *S*s with higher Amp. MPs, as would be expected from the correlation of plus .80 between Variability (absolute amount) MP and Amp. MP.

Action potentials similar to those occurring at the moment of reaction were observed to occur at the moment of stimulation. They were obscured on the photographic record by the presence of the stimulus input signal. The investigator did not elaborate systematic controls to insure their validity as muscle potentials, but holds their existence to be reasonably certain because of their presence on photographic records without the input signal. Needless to say, any systematic investigation of the relation of peripheral MPs to RT would need at some point to define, measure and relate these additional action potential phenomena which were outside the scope of the present investigation.

Discussion

It seems clear from the results of the present investigation that the presentation of the simple RT task, under conditions of practice providing competitive incentives and knowledge of daily performance, may give rise to either positive or negative increments of Amp. MP, which vary widely in magnitude. It is also clear that improvement may occur in Perf. RT regardless of the sign of the increment in Amp. MP. Therefore, Dunlap's hypothesis (9) requires some revision if it is to be consistent with the results of this particular investigation. However, the influences of three incompletely controlled variables in the present experiment need consideration before productive revision can occur. Each variable will be discussed in relation to the revision which it suggests.

Stimulus intensity.—In this experiment the intensity of the stimulus lamp was inadvertently allowed to diminish from about six to one foot candles, over a period of approximately seven months. Hence the intensity was a little less for each successive group of *S*s. The effect of this intensity loss on Perf. RT was readily observed as an increase in the latency of the reaction. However, the effect of stimulus intensity loss on Impr. RT, Amp. MP or Incr. MP, as separate from motivational effects caused by a knowledge of poorer performances, needs to be determined by an experiment holding the motivational variables constant while varying the stimulus intensity among practice groups.

It would also seem reasonable to expect that the change in stimulus intensity would produce some pattern of concomitant variation in the amplitude of the MP occurring at the moment of stimulation. It would also be reasonable to expect some form of concomitant variation between the MP occurring at the moment of stimulation and the MP at the moment of the reaction. These relationships when determined by experiment might well provide an important clue for a modification of the hypothesis.

Finally, it would seem reasonable to expect that in *S*s uninstructed for set and unpracticed in RT, higher stimulus intensities would tend to result in a preponderance of either sensory or motor sets, and lower stimulus intensities, the opposite set. Inasmuch as the preponderance of sensory or motor sets may prove of primary importance in accounting for the mixed Incr. MP tendencies in the present study, this possible result of variations in stimulus intensity should be tested.

Sensory vs. motor sets.—The *S*s were instructed to attend to both the stimulus and the finger movement. Under

such neutral instructions either sensory or motor sets presumably could have occurred. The present writer would like to offer the hypothesis, based on the results of a small auxiliary experiment suggested by Dunlap, that motor sets correlate with positive increments in Amp. MP, and sensory sets correlate with negative increments in Amp. MP, with practice in simple RT.

According to this hypothesis, the sign but *not the magnitude* of the increment is related to the distinction between sensory and motor sets. If this hypothesis should be verified, and it certainly requires conclusive experimental verification, additional questions concerning the relationship at once present themselves. Assuming that motor sets facilitate generalized muscular contraction in the reaction, why should the heightened generalized contractions not be present earlier in the practice sessions? On the other hand, assuming that sensory sets tend to diminish generalized muscular responses in the reaction, why should heightened contractions be present at all in the earlier practice sessions? Before these questions can be answered it seems probable that the sign of the increment of the other major action potential observed in the present study, the one occurring at the moment of stimulation, will have to be determined, and its relation to the potential at the moment of reaction made clear.

Incentives.—Presumably, all the *Ss* of this investigation were responding to nearly maximal incentives. They were trying to better their records from day to day; to do better than their competitors in the group; and to reach their maximum performance within the time limit of three weeks. They knew that the accepted standard for simple RT, light stimulus, was 200 msec. All of the *Ss* of the last two groups for whom the intensity of the stimulus had considerably diminished knew that their performances were considerably inferior to this criterion.

It seems reasonable to hypothesize that practice under such maximal incentive conditions would result in positive increments in Amp. MP as the situation became more critical for the *S* with the passing of each additional practice session. Something resembling this effect was observed in the last group, presumably those with the highest incentives, because of the very poor initial performances resulting from the seriously diminished stimulus intensity. This group had the largest positive increment in Amp. MP of any of the five groups.

The weakness of such an hypothesis is that it does not account for the negative increments in six of the 25 *Ss*. The only way to meet this difficulty is to bring in the aforementioned sensory-motor set hypothesis, and maintain that while maximal incentives increase the probability of motor sets and hence positive increments, other factors of unknown nature and origin tending toward sensory sets may be sufficiently strong in a minority of *Ss* to preclude this outcome. It is readily seen that this hypothesis requires two independent principles to account for all of the data, and hence does not meet the requirements of parsimony. The hypothesis has been stated in order to emphasize the following question—is the concept of simple perceptual motor learning as dependent on the elimination of unessential muscular components of a generalized response compatible with the concept that incentives facilitate the muscular components of a response? An experiment is certainly in order which is designed to vary in-

centives systematically, while holding set and stimulus intensity constant, and observe the resultant signs of the increment of Amp. MP with practice.

The more obvious and more promising hypothesis concerning the relation between incentives and Incr. MP is that *the incentive relates to the magnitude of the increment rather than its sign.* This hypothesis is based on and is in complete agreement with the results for the secondary object of the investigation, in which it was found that relative Impr. RT bore a curvilinear relationship to relative Incr. MP which was independent of the sign of the increment.

According to this hypothesis, minimal incentives would relate to minimal Incr. MPs, either positive or negative; and minimal Incr. MPs would relate to medium degrees of relative Impr. RT. In contrast, maximal incentives would relate to maximal Incr. MPs of either sign, and the latter would relate to either maximal or minimal relative Impr. RT. The basic process in simple perceptual motor learning would then be the *rate* of either elimination or facilitation of unessential muscular components of a generalized muscular response. The nature of the set required by the task would be left to account for the sign of the increment. It is quite conceivable that the nature of the set could shift at any point in a practice series, depending on the specific requirements of the task and the order in which they must be met by the *S*.

If this incentive-rate and set-sign hypothesis for Incr. MP should be verified for practice in simple RT by further experimentation, it would be of importance to test it in a more general way for its relevance to the results of other experiments relating expressed tension to practice effects in such divergent tasks as mirror-drawing (18), stylus mazes (3, 17), pursuit-rotors (11), mental arithmetic (5), and memorization of nonsense syllables (11).

Conclusions

1. The presentation of the simple reaction time task, under conditions of practice providing competitive incentives and knowledge of daily performance, may give rise to either positive or negative increments of Amp. MP which vary widely in magnitude.

2. Improvement may occur in Perf. RT regardless of the sign of the increment in Amp. MP.

3. Dunlap's hypothesis requires revision if it is to be consistent with the results of this investigation.

4. The influences of three incompletely controlled variables in the present experiment, stimulus intensity, set, and incentive, need investigation before productive revision of the hypothesis can occur.

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ADAPTATION OF THE MUSCULAR TENSION RESPONSE TO GUNFIRE

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The photographic study of the startle response as made by Landis and Hunt (4) showed no well defined pattern of habituation with repetitions of the stimulus. The eye blink was never subject to habituation and the head jerk seldóm so (no quantitative studies were made). Other components adapted out with some subjects and not with others. The speed of adaptation also varied. Davis (2), using sounds of about 100 decibels, found a significant adaptation factor. Later work by Davis (1), in which larger responses were evoked, found little. It seems likely, in the light of the work thus far reported, that habituation may be a function of the size of the response: Large responses do not adapt out as readily as smaller ones. The present investigation deals with the very large responses resulting in the presence of very loud sounds.

Davis (2) describes two responses to auditory stimulation: the a-response and the b-response. Landis and Hunt (4) indicate that after the startle response the individual has returned to a normal state after about one and a half seconds. Davis (2) using a continuing stimulus found the b-response extending beyond this period. In fact, after 4½ sec. (measured from stimulus onset), the level of tension was still above that of the prestimulus period.

Procedure

A group of nine subjects was used in this study. All subjects were right handed. Subjects lay in a relaxed position in a specifically constructed shielded box 3 × 3 × 7 feet. (The usual shielded cage could not be used because of its proximity to the amplifiers. Firing a 32 caliber round of blank ammunition produced microphonics in the system.) The recording technique was the same as that used in the preceding study.

Subjects were given about a five-min. relaxation period. They were told that at the end of such an approximate period a round of 32 caliber blank ammunition would be fired. After each round the experimenter had to enter the room with the subject to cock the revolver. The interval between rounds was two min. Subjects were instructed to remain as relaxed as possible throughout the entire period and to make no voluntary response to the stimulus. They did not know the number of rounds to be fired or the length of the intervening interval.

Presentation of the stimulus was synchronized with the activation of the integrator relays (3). A switch on the control panel was closed to operate a heavy duty relay which fed DC current to a strong solenoid of the shear pin type. This operated a lever against the trigger, thus firing the revolver. An argon flash bulb served as a stimulus signal on the film. (The presence of the heavy duty relay and the solenoid in the circuit produced a time delay of about 30 msec., measuring from the onset of the argon signal light. This was calculated from the microphonic waves present in early exploratory work.)

The recording camera was started about one sec. before the stimulus was given and continued recording for at least seven sec. after the round was fired. The use of the integrators divided each trial into periods of 0.1 sec., with the amount of potential for each of these periods summated. A calibration record was made by integrating a 100 cycle standard voltage, and records were measured in the manner described (1). Readings were made for the five periods of 0.1 sec. preceding the stimulus presentation and for 7½ sec. following.

Results

Latency.—The response begins to appear some time during the 0.2 sec. after the stimulus presentation. The maximal height of the response is reached during the 0.3 sec. after stimulus presentation. It then begins to

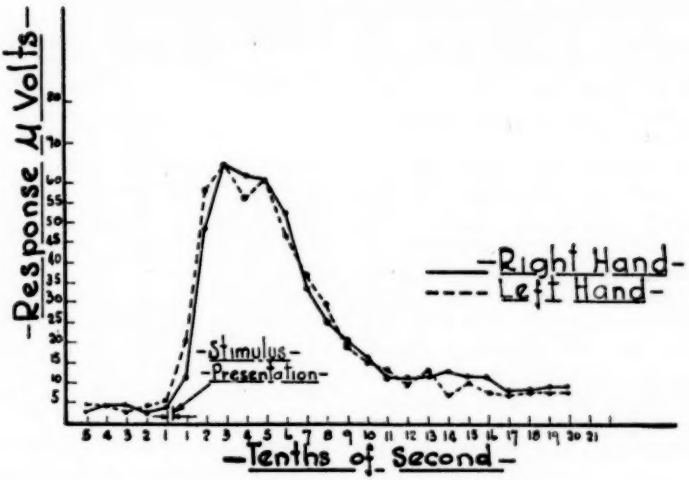

FIG. 1. Mean response curve to gunfire

drop off rapidly, but not as rapidly as its rise. Cumulated potentials after 1½ sec. are still more than twice those during the pre-stimulus period. For a graphic presentation of the first two seconds of the response for both right and left hands see Fig. 1.

Adaptation.—The method used by Davis (2) to determine adaptation in the a- and b-responses was applied here. A three-factor analysis of variance (between subjects, between trials (adaptation), and residual) was made. Fig. 2 shows the mean increment in microvolts for each trial. For the right hand, trial five shows a decrease in response of 13 microvolts, or 15 percent. For the left hand, there is an increase in trial five over trial one of 4.23 microvolts, or 6.5 percent.

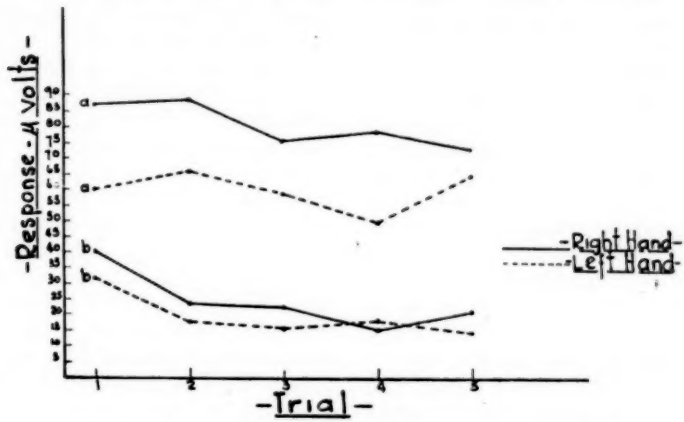

FIG. 2. Mean response amplitudes by trial for a- and b-responses

The adaptation factor is found to be non-significant for either hand. For the right hand the *F*-value is 1.18 and for the left hand the *F*-value is 1.26; at the five percent level the significant *F*-value is 2.74.

If we consider the b-response (1.0 to 1.8 sec.) for adaptation, we find somewhat comparable results. The method was the same as for the a-response. Fig. 2 also shows the mean response in microvolts for each trial. For the right and left hand there is a decrease, but the decrease is significant for the right hand only, and that at the five percent level of confidence. However, there is an apparent trend for the left hand also.

The level of tension from 2.0 sec. to 7.0 sec. continues at a level higher than that of the pre-stimulus period and does not adapt out. By the same method of analysis as that used for the a-response we have examined three periods for adaptation effects: 2.0 to 3.0 sec.; 4.0 to 5.0 sec.; and 6.0 to 7.0 sec. In no case was a significant *F*-value found. The continuation of a high level of tension for a substantially long period after stimulus presentation seems to be a regular feature of the response pattern. Measured in this way a statistically significant adaptation is found in only one case (the b-response in the right arm).

But adaptation may be shown in another way. The mean response for each stimulus presentation shows a marked difference from trial to trial. The difference is not so much in terms of the amplitude of the response but in terms of the duration. To test this the maximum amplitude for a given trial was taken, irrespective of the 0.1 sec. in which it occurred. This value was divided by two. It was then determined at what nearest 0.1 sec. this amplitude occurred. These values are shown in Table I. An analysis of

TABLE I

THE 0.1 SEC. IN WHICH MAXIMUM RESPONSE ÷ 2 OCCURS

	Trial	Maximum Response (microvolts)	Maximum Response ÷2	Time 0.1 sec.
Right Hand	I	81	40.5	10
	II	70	35.0	7
	III	61	30.5	7
	IV	68	34.0	7
	V	64	32.0	6
Left Hand	I	68	34.0	9
	II	74	37.0	7
	III	59	29.5	8
	IV	57	28.5	6
	V	73	36.5	8

variance for this durational factor shows a decidedly significant adaptation factor. For the right hand the calculated *F*-value was 16.31, and for the left, 6.63. For the degrees of freedom allowed, an *F*-value of 6.124 is significant at the 0.1 percent level. On the basis of the durational characteristic of the a-response we must conclude from this experiment that there is adaptation. The downward trend of the amplitude, though generally non-significant, confirms the statement. The responses here are large and their adaptation small. Thus there is confirmation of the suggestion that large responses resist adaptation.

Differentiation of a-response and b-response.—A comparison of our results with those of Davis extends the description of the a-response and b-response. With the larger and longer responses in this study the maximum is reached later, since the mean response is in the 0.3 sec. period. The b-response is also larger than in the Davis's study but here ranges from one-half to one-quarter of the size of the a-response, instead of being equal to it. The two are evidently affected differently by the stimulus variation. How long it (or its successor) lasts is

uncertain, but it is evidently at least 7.5 sec. The length of the a-response also shortens with trials after the first.

Discussion

The results fit the hypothesis that large a-responses do not show much decrease with stimulus repetition. This was also the case for 'large' responses in the Davis's study. In that study, however, the large size of the responses was produced by other conditions than stimulus variation; here it is a matter of stimulus variation. Landis and Hunt's observation that arm movement sometimes disappears with stimulus repetition suggests more adaptation than found here. But of course muscle tension can very well increase without observable movement. The b-response in this study, though larger than in the Davis's studies, behaves in about the same manner with regard to adaptation: it shows a small amount in the right, and possibly in the left arm.

Summary

Adaptation of the muscular tension responses to very loud sounds was studied by measuring action potentials from both forearms as subjects were stimulated by the firing of 32 caliber blanks at intervals of two min. The results obtained were:

1. There occurred an initial response (a-response) with a latency of about 0.1 sec. and a maximum at about 0.3 sec. and 60 to 90 microvolts in mean size.
2. There was a substantial, though much smaller tension increment in the 'b-response' period, 1.0 to 1.8 sec. after the stimulus, persisting at least to 7.5 sec.
3. For the a-response, adaptation for size is not significant; for duration, it is significant.
4. For the b-response the adaptation effect (for size) is significant for the right arm; it may be present, but small, for the left.
5. The results fit the hypothesis that large responses of this sort resist adaptation.

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A NOTE ON REACTION TIME AS A TEST OF COLOR DISCRIMINATION [1,2]

BY J. DAVID REED

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Evidence for color deficiency traditionally has rested upon the presence of errors in responses to stimuli of varying hue. While the time allowed for such responses is often controlled, the reaction time required to make the responses is not measured in tests for color deficiency. This paper reports a study (made for another purpose) which suggests the usefulness of reaction time as a technique for testing color vision. It is based on the known fact that reaction time increases as the difficulty of discrimination increases (2).

In the conventional type of test, the person who is color blind reveals his deficiency by making 'wrong' responses when required to differentiate between colors. The 'wrong' responses, of course, are really wrong only insofar as they would be judged differently by a person with normal sensitivity to hue, since 'wrong' is equal to 'indistinguishable' for the color blind. In estimating the *degree* of color deficiency in any given individual, however, methods based on the number of errors have always been inadequate, because a numerical measure of degree must necessarily depend on a simple count of the number of times a person makes wrong responses in various discrimination situations. When, therefore, we have the opportunity to detect differences between normal and color blind subjects which are not shown up in error scores, we may be justified in assuming that these differences are of a more subtle character and thus offer a more sensitive measure of color deficiency.

Such an opportunity was afforded during the war in the course of research at the Submarine Base, New London, Connecticut, on color deficiency found in naval personnel. The larger aim of the research was to determine standards of color discrimination requisite for submarine duty, and to construct tests suitable for screening those lacking the necessary proficiency.

Apparatus

These observations were made on color blind [3] and normal subjects who were faced with a discrimination problem involving a submarine 'Christmas Tree.' This is a panel approximately 18 in. square containing 48 jeweled lights, half red and half green. The arrangement of these colored jewels was modified in order to eliminate rows of all green or all red which normally appear on this device. The observer sat directly in front of the panel, at a distance of about three

[1] The writer wishes to express his appreciation to Capt. C. W. Shilling (MC) USN and to Mr. Dean Farnsworth, under whom this study was carried out at the Medical Research Laboratory, Submarine Base, New London, Conn.; also to Mr. Walter Granville, now of the Container Corporation of America, for spectrophotometric analysis of the filters used in the study.

[2] Opinions expressed in this article are those of the author and are not to be construed as official or as representing the views of the Navy Department or of the Naval Service at large.

[3] The color blind group was made up of applicants for submarine service who had failed the American Optical Company Pseudo-Isochromatic Plates, the Navy Lantern, and the Farnsworth Dichotomous Test (1). The latter test also established the type of color deficiency, protanomaly or deuteranomaly, of each observer. Both types are represented in the color blind group. The two types behave alike in this particular test situation because they display the same confusions with the red filter. For that reason the data from the two types were treated together.

feet. In front of him were two telegraph keys, the left labelled 'Different,' and the right labelled 'Same.' He was told to depress the 'same' key when all the lights were the same color, whether red or green, and the 'different' key when they were not. Depressing either key broke the clutch circuit of a timer and stopped the clock.

While two categories of same (all red or all green) and two of different (23 red and one green or 23 green and one red) existed, the subject was merely required to discriminate in terms of same and different. The experimenter said 'Ready' from one to two sec. before the lights were flashed on.

The reaction time of each trial was recorded in hundredths of a sec. and a record was made of each erroneous response.

Results and Discussion

A preliminary experiment was run, with the lamps burning at their rated voltage, yielding a color temperature of approximately 2848° K. The particular green jewel used in this experiment was not confused with the red by the color blind observers because,

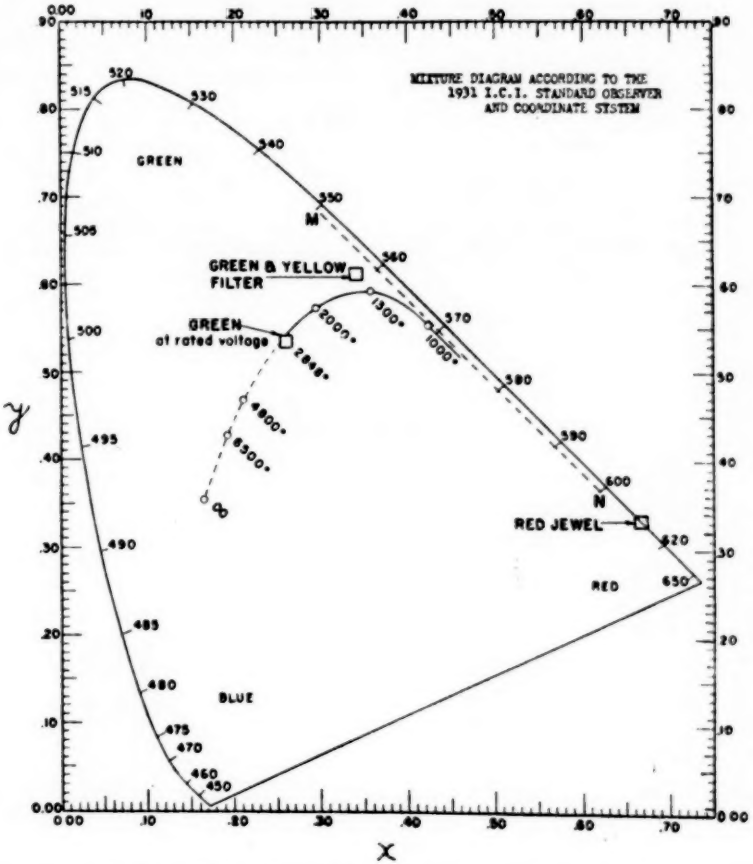

Fig. 1. Locus of color of green jewel of Christmas Tree computed for different color temperatures of the illuminant. As the voltage on the lamp is reduced, the green becomes progressively yellower.

while it appeared green to normals, it transmitted a certain amount of blue as well as green and yellow. A deuteranope or protanope would be able to distinguish it from the red by the bluer characteristics. Time scores showed some slight advantage for men with normal color vision, while the color blinds made fewer errors than the normals. Neither difference is statistically significant.

Our real problem was concerned with the fact that on submarines these lamps are not uncommonly burned at a reduced voltage by means of a dimmer. This causes a change in the color of the lamp and thereby in the color of the jewels; the green becomes more yellow while the red remains essentially the same color. When the green color is made more yellow, it is more readily confused with the red color by a color blind subject. This is illustrated in Fig. 1 in which the line m–n represents a confusion line for color blind individuals. Any color which plots on this line could be confused with red by both protanopes and deuteranopes. The closer a color is to this line, the more readily it is confused with the red. The curved line on the diagram is the color locus calcu-

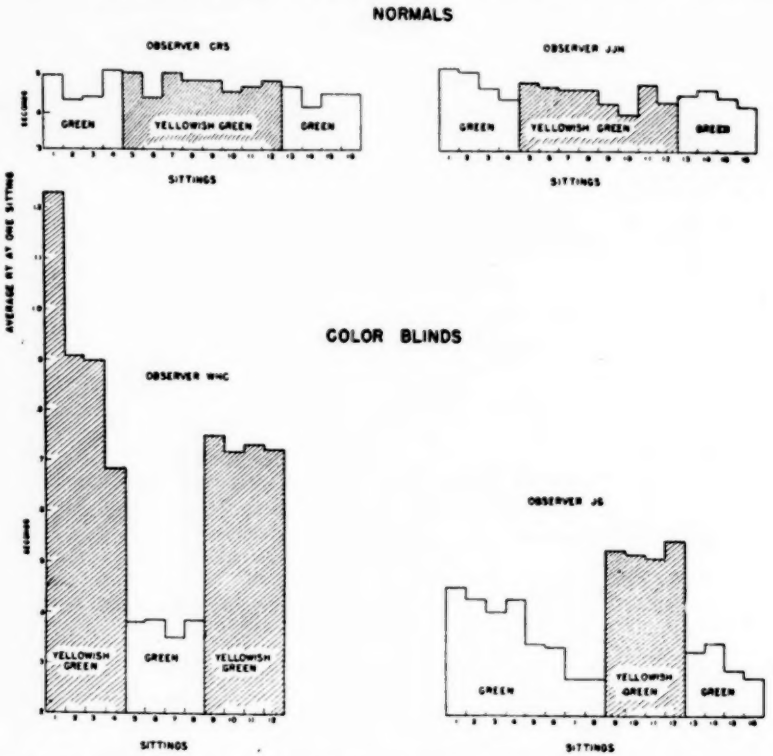

FIG. 2. Average reaction times made by typical normal and color blind men to green and to yellowish-green jewels in the Christmas Tree. Each observer was given 23 trials at each sitting and the reaction time shown at each step in the graphs is the average of the 23 reaction times made at that sitting.

lated for the green filter at different color temperatures. Note that as the voltage of the bulb is lowered the green becomes increasingly more yellow and approaches as a limit the confusion line of the red.

It was difficult to obtain a constant, reproducible reduced voltage level on the experimental device and practically impossible to make direct spectrophotometric measurement of the emitted light. Therefore, the color effect was duplicated by the use of modifying filters which were constant, reproducible, and measurable. A yellow gelatin filter was inserted behind each of the green jewels. The combination is not identical with the color obtained from attenuating the voltage, but it is very similar. The position of the combination, plotted here, is seen to be approximately that of the green jewel illuminated by a lamp whose color temperature is 1300 degrees K. The resultant color is not as yellow as can be obtained by the use of the dimmer controls on a submarine and hence represents an intermediate rather than an extreme condition. To compensate for the reduced brightness of the green, a neutral gelatin was inserted behind the red jewels.

Since the combination of green and yellow is closer to the color blind confusion line with red, we would predict that the greater difficulty in distinguishing the two would result in increased reaction times. This prediction is borne out by experimentation. Fig. 2 is a graph of the data from two representative color blind and two representative normal subjects. Each column is the arithmetic mean of 23 judgments. The color blinds show immediate and obvious increases in reaction time, while the men with normal color vision suffer no decrement under the same condition.

The error scores once again show no significant difference between the two groups of subjects, with a slight advantage favoring the color blinds.

Conclusions

We thus see that throughout the experiment error scores remained constant and low, and in no wise differentiated the color blind from the men with normal color vision. This is in agreement with the known ability of color blinds to identify saturated colors if given ample time. On the other hand, the use of a reaction time measure immediately showed the increased difficulty of the discrimination for color blinds. Therefore it is probable that some test for color deficiency which uses reaction time may be able to differentiate degrees of color deficiency better than one using error scores.

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AN ANALYSIS OF THE UNIT OF MEASUREMENT OF THE GALVANIC SKIN RESPONSE[1]

BY OLIVER L. LACEY AND PAUL S. SIEGEL[2]

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Introduction

Our problem is to select an appropriate unit for specification of the galvanic skin response (GSR). The natural unit would appear, of course, to be straightforward change in resistance. For example, if a subject's basal resistance is 50,000 ohms under resting conditions and drops to 40,000 ohms upon the application of some 'exciting' stimulus, it seems proper to express the GSR as 50,000–40,000, or 10,000 ohms. However, other possibilities exist. The GSR could equally well be expressed as a change in conductance. In this case the basal conductance would be $(1/50{,}000) \times (10^6) = 20$ micromhos, the new conductance would be $(1/40{,}000) \times (10^6) = 25$ micromhos, and the GSR would be five micromhos. Similarly, additional units are available, such as the logarithm of the conductance change, the logarithm of the resistance change, the percentage change in resistance, the percentage change in conductance, and so on. Any, or all, of these units may serve as modes of expression of the GSR, and, since they are interconvertible, all convey the same meaning in the final analysis. The question we raise is this: which of the many possible units, may be in some sense 'best' for expression of the GSR?

This problem has been attacked most directly and most recently by Haggard (3). He summarizes the units proposed by earlier investigators and, as a result of his study, suggests a further logarithmic unit derived from the regression of GSR upon conductance for each individual. In the same paper Haggard sets forth four useful criteria for the examination of possible units. He states that a satisfactory unit should enable one:

1. To make the necessary mathematical transformations with a maximal degree of simplicity and a minimal number of computational errors.
2. To speak of individual differences among *Ss* under comparable experimental conditions as well as differences among groups of *Ss* receiving variations in experimental treatments.
3. To speak of the general level of background excitation (general level) independently of the particular reaction (GSR) which, as a result of a specific stimulus or set of stimuli, is superimposed on the pre-existing level of excitation.
4. To use such statistical techniques as product-moment correlation, *t*-tests, analysis of variance, etc. In using these methods of analysis, one makes the implicit assumption that his scale of measurement possesses units of equal size over its total range.

With these criteria we agree in general, but feel that the fourth requires amplification. One major point is the need for expression of data in such a form as to be amenable to statistical treatment. And, since a basic assumption in almost all common statistical techniques is that the parent population is normally distributed, we may restate this point as a requirement that the scores expressed in an appropriate unit *must not deviate significantly from normality*. This we shall refer to as the criterion of normality.

[1] This research was supported in full by the Research Committee of the University of Alabama.

[2] A preliminary report of this investigation was presented by the writers at the 1947 meetings of the American Psychological Association.

Haggard's statement of his fourth criterion includes also a demand for units equal in size over the total range. This requirement is best clarified by an example. If one subject declines in resistance from 100,000 to 90,000 ohms and another declines in resistance from 50,000 to 40,000 ohms, do these two GSR's, each of 10,000 ohms, mean the same thing? If the magnitude of the GSR depends on the basal level, obviously they do not. What is needed is a unit in terms of which GSR scores are independent of level—i.e., the GSR scores *must not correlate significantly with the basal level.* Only in this way can a valid comparison of GSR's be made between *Ss* of differing basal level. This requirement we shall designate as the criterion of independence.

Our problem thus may be specified as an examination of several available measures of the GSR to determine which, if any, may fulfill both criteria.

Method and Procedure

The experimental design followed three steps:

1. The basic level of resistance and change in resistance following an electric shock were determined in 92 male *Ss*.

2. The results were expressed in terms of each of eight units; change in resistance (R), change in conductance (C), % change in R, % change in C, change in log R, change in log C, log change in C, and the unit proposed by Haggard (H).

3. The distribution of scores in terms of each unit was examined first, for independence of basal level, and, second, if satisfactory in this respect, for normality of distribution.

The experimental details were as follows:

1. *Subjects.*—The sample investigated consisted of 92 men from an elementary psychology class. These *Ss* were divided into five groups according to the experimenter concerned and the period of testing. This division seemed wise in view of the possibility that basal level and/or GSR might depend upon the experimenter or the time of day of testing. The details of the division are shown in Table I. The *Ss* as a whole ranged in age from 18 to 33 years, in weight from 120 to 206 lb., and in height from 65 to 77 in.

2. *Apparatus.*—The basal resistance levels and the GSR's were determined by means of a

TABLE I

Basal (C_1) and Maximum (C_2) Conductances in Micromhos

Siegel 12:00–1:00 $N = 20$		Siegel 2:00–3:30 $N = 21$		Siegel 3:30–5:30 $N = 18$		Lacey 2:00–3:30 $N = 16$		Lacey 3:30–5:30 $N = 17$	
C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2	C_1	C_2
43	94	23	40	31	53	23	43	63	72
10	20	23	35	59	87	50	65	91	102
43	87	50	78	53	74	71	89	38	67
17	23	91	118	42	63	48	61	53	65
43	57	63	80	17	21	48	62	143	179
20	37	33	41	200	210	59	66	50	66
40	60	12	18	42	68	67	80	50	80
38	68	22	49	34	40	125	138	77	85
28	63	50	63	67	74	71	78	71	92
13	23	38	56	31	46	33	46	26	32
43	70	36	60	83	114	91	105	91	111
36	57	43	55	71	83	40	55	14	30
91	107	38	51	50	68	91	109	100	120
34	62	27	33	91	100	40	49	56	69
59	66	32	43	71	91	83	102	32	43
59	81	83	102	40	49	71	80	50	86
29	47	30	38	33	52			83	120
45	80	26	42	59	71				
59	66	48	64						
34	53	91	100						
		33	56						

potentiometric circuit described elsewhere (5). The subject was connected into this circuit via two Darrow Universal Electrodes. These electrodes filled with Sanborn Redux Electrode Paste were attached to *S*'s palms. The electric shock (which was described by the *S*s as 'fairly intense') was delivered from an inductorium by way of two similar electrodes attached to the dorsal surface of the left forearm.

3. *Experimental procedure.*—Each *S* was seated comfortably in a chair. The electrodes were attached and the following instructions read:

> Please sit quietly with your eyes closed and relax. I can answer no questions about this experiment now but I can tell you that we are interested *solely* in the skin resistance of a large sample of college students.
>
> Coughing or clearing your throat will disturb the record. If you feel any inclination to do so, please clear your throat now. All right, sit quietly now and relax.

The instrument was then switched on and the current through *S* held at 40 microamperes. At the end of 60 sec. the first reading of general level was noted. Five further observations of level were made at 30-sec. intervals. The shock was delivered as the sixth observation of level was made. The maximum microammeter deflection occurring within the following 30 sec. was noted and the further instructions given to *S*:

> You will not be shocked again—just try to relax.

Four further microammeter readings were noted at intervals of 30, 60, 90, and 120 sec. after the administration of shock. The *S* was then released and requested not to disclose the details of the experiment.

Results

The raw data are presented in Table I. The basal conductances shown in this table are those noted at the instant the shock was administered. The maximum conductances shown are those indicated by the maximum microammeter deflection during the 30 sec. following shock. The individual GSR's are readily obtained in terms of the particular units by straightforward arithmetic manipulation of the two values.

The results of analysis of these data are shown in Tables II and III.[3] We shall deal with them in two sections: the first concerned with the criterion of independence; the second, with the criterion of normality.

1. *Independence.*—It will be recalled that a highly desirable characteristic of an acceptable unit is that the scores it provides shall prove independent of the basal level. Only in terms of such a unit can valid comparisons of the magnitudes of GSR's of *S*s differing in basal level be made. The absence of independence can be detected most easily by straightforward correlation of GSR with basal level. If such a correlation coefficient proves significant we can no longer entertain the null hypothesis of independence of GSR and basal level. Table II shows the results of such a check. The GSR scores expressed in terms of the first seven units under investigation have been correlated in each case with the basal level of subject conductance. As may be seen from the table, only change in conductance and log change in conductance are acceptable units in terms of this criterion. To these two, however, must be added the unit proposed by Haggard. This unit is achieved essentially by fitting a regression line describing the log of the GSR in ohms as a function of basal level, and then expressing the individual scores in terms of deviation from regression. Scores so derived are thus, by definition, independent of level. Three units, therefore, satisfy the criterion of independence: change in C, log change in C, and the unit suggested by Haggard (H).

2. *Normality.*—The three units fulfilling the criterion of independence were examined for normality by com-

[3] We are indebted to Miss Helen L. Stuckey, a graduate student in the Department of Psychology, for checking the statistical computations.

TABLE II

CORRELATION OF GALVANIC CHANGE WITH BASAL LEVEL OF CONDUCTANCE

Unit	Siegel			Lacey		Combined* (df = 77)
	12–1 (N = 20)	2–3:30 (N = 21)	3:30–5:30 (N = 18)	2–3:30 (N = 16)	3:30–5:30 (N = 17)	
Change in resistance (R)	−.79	−.73	−.65	−.70	−.64	−.71**
Change in conductance (C)	.08	.25	−.08	.00	.35	.05
% change in R	−.61	−.57	−.63	−.68	−.44	−.59**
% change in C	−.54	−.53	−.53	−.68	−.54	−.56**
Log change in R	−.91	−.90	−.74	−.85	−.85	−.86**
Log change in C	.08	.28	−.02	−.01	.34	.14
Change in log R	−.58	−.55	−.60	−.68	−.59	−.60**

* The combined correlation coefficients have been obtained by the method described by Fisher (7, pp. 209–210).
** Significant (P = .01 when r = .28, for 77 df).

TABLE III

SKEWNESS AND KURTOSIS OF SCORES IN TERMS OF UNITS INDEPENDENT OF BASAL LEVEL OF CONDUCTANCE

Unit	Siegel			Lacey		Combined Probability*
	12–1 (N = 20)	2–3:30 (N = 21)	3:30–5:30 (N = 18)	2–3:30 (N = 16)	3:30–5:30 (N = 17)	
Change in conductance (C)						
g_1	.80	.40	.24	−.17	.56	
P	.06	.22	.32	.88	.16	.28
g_2	.20	−.91	−.94	−.71	−1.42	
P	.92	.17	.19	.26	.09	.32
Log change in C						
g_1	−.23	−.30	−.66	−.67	−.04	
P	.38	.32	.10	.10	.48	.30
g_2	−.54	−.82	−.45	−.39	−1.02	
P	.30	.20	.39	.38	.18	.21
Haggard's unit						
g_1	−1.63	−2.88	−1.45	−.64	−.93	
P	<.01**	<.01**	<.01**	.12	.04**	<.01**

* The combination of probabilities has been made following the technique described by Fisher (7, pp. 104–106).
** Significant

puting the familiar g_1, and g_2 statistics, g_1 indicating skewness, and g_2 kurtosis (2). In each case the distribution in terms of the particular unit was analyzed first for skewness and, if satisfactory in this respect, for kurtosis. The results of the analysis are shown in Table III. Both change in conductance and log change in conductance are satisfactory with respect to normality. The distribution of scores in terms of the unit proposed by Haggard, however, shows a marked degree of skewness.

It seems clear that in terms of our two criteria, only change in conductance and log change in conductance are appropriate for specification of the GSR. In view of the fact that computation of log change in conductance involves an extra arithmetic step, it

would appear preferable to utilize change in conductance as the more convenient of the two acceptable units.

Discussion

The foregoing statistical analysis would appear to justify the following conclusions:

1. For specification of the GSR, change in conductance is both methodologically acceptable and convenient in computation.

2. Log change in conductance is also acceptable, but is less convenient in computation.

3. Change in resistance, % change in resistance, % change in conductance, change in log resistance, change in log conductance and Haggard's logarithmic unit are not acceptable.

These conclusions seem straightforward. Two precautions, however, seem worthy of mention:

1. We cannot claim to have *proved* that the units found acceptable are normally distributed and uncorrelated with basal level—rather, as in all cases of statistical sampling, all that can be said is that the particular null hypotheses (in this case, of distribution normality and independence) are not significantly violated. Since, however, we have 92 cases available for examination of the hypotheses, it would appear that a fair chance has been given for the detection of any considerable deviation from distribution normality or marked correlation. It seems safe to conclude, that any deviations from normality or correlation with basal level which may exist in the distributions of these units must be relatively unimportant. The application of ordinary statistical treatments will introduce no significant error.

2. The results are not to be interpreted as implying that change in C or log change in C must inevitably be used for expression of the GSR. As we have previously indicated, an experimenter is free to use whatever well-defined unit he chooses, *provided* he applies an appropriate statistical technique for testing the significance of his results. For example, Festinger's test (1) for evaluating the significance of differences between samples from skewed populations might well be satisfactory in some instances. If, however, some unit other than those found acceptable here, is chosen, then the experimenter should satisfy himself (and his readers) that his sets of measurements do not violate the underlying assumptions of whatever statistical technique he employs. The units found acceptable here, on the other hand, may be used with reasonable assurance that the commoner types of statistical treatment are appropriate.

It is interesting to note finally that an earlier study (4) has indicated that conductance is an acceptable unit for the expression of both basal level and long term changes in basal level. In view of these results, the present finding that change in conductance is satisfactory for expression of the short-time changes of the GSR suggests a rather wide general utility for conductance measures in the study of skin resistance.

Summary

The palmar skin resistance levels and galvanic skin responses of 92 male Ss were determined in an effort to discover which of several possible units for specifying the GSR might be appropriate. The units investigated were change in resistance, change in conductance, % change in

resistance, % change in conductance, change in log resistance, change in log conductance, log change in resistance, and a logarithmic unit suggested by Haggard. The units were tested for acceptability by two criteria: 1. Independence—In order that GSR's obtained from *Ss* differing in basal level may be validly compared, the GSR scores must be independent of basal level. 2. Normality—In order that data may be amenable to ordinary statistical treatment the GSR scores must not violate the assumption of normality in the parent population. The results obtained indicate that only change in conductance and log change in conductance are acceptable in terms of these two criteria. In view of the greater ease of computation of change in conductance this measure is recommended as the appropriate and convenient unit for specification of the GSR.

(Manuscript received January 10, 1948)

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